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THE PHOTOGRAPHIC NEGATIVE



Herbert C. McKay, F. R. P. S.

The
PHOTOGRAPHIC
NEGATIVE

by

HERBERT C. McKAY, F. R. P. S.

IN FOUR VOLUMES
VOLUME 1

LITTLE TECHNICAL LIBRARY

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To
FRANCES ADAMS MCKAY
*without whose constant support and encouragement this
work would hardly have been completed.*

INTRODUCTION

THE photographer of seventy-five years ago had only his camera, some sheets of plain glass, and a supply of chemicals to work with! He had to understand every step in preparing his sensitive plates and developing his negatives, or he made no photographs. Actually he was more proficient than many present-day photographers.

This is no plea to return to the days of the wet plate and plain salted paper. There has been no invention or discovery in photography that has not added value to the art. The only misfortune lies in the fact that as the manufacturer took over more and more of the responsibilities, the photographer concluded that there was no necessity for him even to understand these steps. The consequence is that the average amateur today regards the production of the negative as a purely mechanical procedure.

No one who holds this conception of photography can produce good photographs and do it consistently. The production of the negative remains one of the most important practical steps in making pictures with the camera. Given a fixed subject and lighting, a dozen competent photographers will produce a dozen different negatives, all good. The beginner can never expect to become a true master photographer until he has mastered negative making. Therefore, it is the purpose of this book to explore thoroughly all of those highways and byways which have a bearing on the subject.

The treatment which has been attempted is one that can be grasped by anyone, including those who have had no formal training in physics, chemistry, or mathematics. This has made it necessary at times to use a presentation which may be considered inadequate by those who are qualified in these sciences. There can be no question as to the validity of such criticism. The excuse is that it is better to violate some of the conventions of science to the end that the layman may grasp a view correct in its broad fundamentals, rather than to make such questions a blank mystery through adhering

strictly to the traditional scientific presentation. During more than twenty years experience teaching advanced scientific subjects to students without even high-school educations, this way has proved highly satisfactory.

Familiarity with technique alone has no value. Complete knowledge of each scientific law involved has no value unless it is coupled with practical application. We have too many photographers who do all their photography with a pad and pencil—too many who limit their equipment to camera and darkroom. We need a mixture of the two. Photography without sound theory is a hit-and-miss, highly unsatisfactory procedure. Theory without practical application is just about the most futile thing imaginable.

How, then, is the earnest beginner to proceed? To learn photography you must read about it. Familiarize yourself with the authorities not only of today, but of yesterday as well. Then apply what you have learned, and prove to your own satisfaction that the statements you encountered are true or false. And never forget the one great secret of photography, one that sets it apart from all sciences and most crafts: What is wrong for you may be quite right for the other fellow!

Therefore, this work is presented to you, not as immutable law, but as a series of observations drawn from experience and from authorities new and old—a series of observations set up before you and which you are free to knock down if you choose and if you can. Even if you prove to your entire satisfaction that something is wrong, you will have gained invaluable experience in formulating that proof, so in either case you are the gainer.

It would be impossible to conclude this introduction without acknowledgement of the kind cooperation received from Agfa Ansco, Eastman Kodak Co., du Pont Film Manufacturing Corp., Defender Photo Supply Co., Mallinckrodt Chemical Works, and other manufacturers. Not only was unlimited data made available, but permission was kindly given to make use of the various publications of these firms for illustrations and information. The writer is also deeply obligated to the whole-hearted assistance of Frank Fenner, Jr., of the Ziff-Davis Publishing Company, for his unremitting vigilance which prevented a small army of minor errors from creeping into the completed work.

HERBERT C. MCKAY

Eustis, Florida
August, 1942

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The Film Emulsion

THERE has been a tendency during the past decade to mechanize the processes of photography; or, what is almost as bad, a tendency to assume that the exercise of manipulative skill is limited to making the print. When we use an emulsion of known characteristics, the exposure meter indicates an unalterable exposure; a standard developing solution is used in fixed concentration, at fixed temperature, and for a fixed time. Whatever may result from these steps is the final negative from which prints of varying character can be obtained only through control of the printing process.

The net result of this attitude toward photography is simply to remove forever the possibility that photography may in time prove its claim to a place among the fine arts. No artist, regardless of his medium, handicaps himself with rules so fixed that his technique becomes invariable. In photography the production of the negative is the one step above all others

which should be marked by the discriminating use of skill on the part of the operator.

It must be remembered that the artist of the flowing tie, long hair, and Bohemian mode of life is not the productive artist. Works of art are produced, as a rule, by hard-working men and women who have a deep love for their work but rarely more than an average conception of their own individual worth. These artists have achieved a mastery of the technical and mechanical phases of their work, and understand the physical limitations of their media. The etcher knows his paper, his inks, his acids; the painter knows which pigments are stable and which are not, which are transparent and which are opaque. He knows when to use canvas and when to use board. These things, like the scales of the musician, are not particularly interesting, but they are vital to the production of the desired result.

The photographer can quite easily—and in fact often does—exercise his skill in composition and lighting. He works sincerely to obtain his picture, and then submits his carefully exposed film to the standardized processing of the commercial finisher. Strangely enough he cannot understand why his picture does not correspond to his original conception. I have no quarrel with the commercial finisher. He has a job to do, and on the whole he does it well. He cannot, under the prevailing scale of prices, give individual attention to each negative; nor has he a mental image of an original subject which would enable him to produce the desired result.

Just what results can be obtained through manipulative development which would be lost under standardized conditions? The question is difficult to answer directly, because the differences are subtle. Perhaps the point is best made by reminding you that among all graphic arts photography has one point in which it

is superlative—just one characteristic which makes it superior to other graphic media. Photography has the power to reproduce graduated tones of such delicacy that they exceed the limits of unaided human perception! So far no other medium having the power to reproduce such infinitesimal changes of tone has been developed! Two negatives may appear identical to superficial observation. One will produce a print of soft, flowing tone, yet the other, regardless of printing manipulation, produces prints of a harshness which cannot be eliminated even by reducing print contrast to the muddy stage.

Often an amateur will remark, "I wish I could make a print like that!" He could if he would realize the fact that **prints of rich quality are made from good negatives.** You won't find a printing demonstrator making prints from amateur negatives. To tell the sad truth he often uses orthochromatic plates—yes, glass plates—and develops them by visual inspection. The old timers had a trick or two. They had to because their materials were far from the high quality which is the rule today. The mere fact that among expert photographers of forty years ago the standard of print quality was, at least from a photo-technical point of view, superior to that of today should indicate that too much dependence upon fixed rules is not good.

The possibilities of manipulation in development might well be explained by an exaggerated example. Using roll film, make a copy of a printed page, and on the same roll photograph a number of cloth samples with the purpose of reproducing texture. Try to obtain good negatives of both exposures without cutting the film and using two developers. This is just the difficulty encountered when using a single emulsion, a single developer, fixed time, and fixed temperature!

In this book we will give our attention to the art

(using that abused word in its true meaning) of negative making, rather than to the science. Naturally, science must do its part and receive due notice. However, formulas are obtainable by the quire from manufacturers, as are booklets and instruction folders. Much of this material is very good, but none imparts the broad experience and knowledge which the photographer gains for himself after a time.

Experience itself is of great importance, but along with that experience there is an intangible which is more important than any choice of developer or emulsion—namely, a definite mental attitude, an approach to the subject which can make it easy or difficult for you to acquire the desired mastery of the negative. This attitude can be suggested, and many hints given, which will make your progress easier. These things I shall try to do in the following chapters, to the end that you will derive from photography the deep pleasure of creative activity—that of making really good photographs, and of bringing into actual existence a picture which you have conceived and executed, and which, therefore, is essentially a part of you.

I would like to repeat a statement made to me recently by a man who perhaps has hung more prints in the great salons of the world than any other individual. "McKay," he said, "you're a technician and like to do a lot of experimenting. I'm a picture maker. For the last twenty years I've used nothing but Verichrome film and no developer but amidol, which I mix with a teaspoon and a kitchen tumbler!"

This man is an amateur; his name would be familiar to you were I to mention it. Our brave engineers may sneer and smile, but the fact remains that this man produces photographs which are definitely better than any I have seen. If some of our commercial photographers could but follow his lead their reputations would soar. I do not recommend his method as stand-

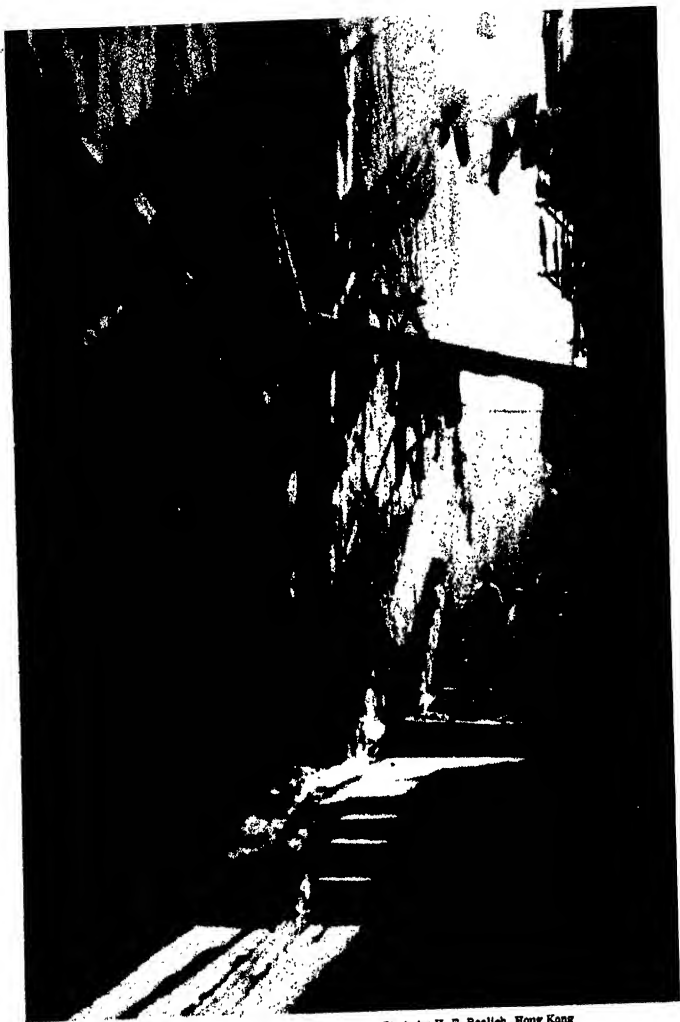


Photo by H. E. Roelich, Hong Kong

Photography is able to reproduce delicate changes of tone.

ard procedure. It takes years of experience, experience founded in the slow-plate-visual-inspection days, to follow such a lead successfully. But it does show that development is something decidedly more individual than merely putting a film to soak in the "soup" until the alarm clock rings!

Origin of the Emulsion.

It is quite obvious that if the negative is to be the subject of discussion, something must be known about the fundamentals of negative production. The logical starting point is the emulsion itself. But this emulsion did not spring, full grown, from the convolutions of a great brain. In fact there was a time when the emulsion was openly sneered at. To go back even further, there was a time when there was no emulsion.

If we were to go back to the cradle of photography we should have several centuries to cover. Daguerre? Well, Daguerre's process was hardly photography except in the sense that blue-printing, gravure, and similar processes are photography. Moreover, there is little doubt that posterity will yield to Niepce full credit for the process known as the Daguerreotype, and to that facile salesman Daguerre the credit which is his due, namely that of ballyhooing Niepce's process sufficiently to make it internationally known. To those who would take up arms I should suggest an impartial reading of the contemporary account as written by Root,¹ which contains the sad truth in letters written by and to contemporary scientists.

But in any event we are not concerned with Daguerre's short-lived process, as it was simply a negative image on metal. Rather let us consider Wedgwood and Davy, who made photomicrographic negatives

¹"The Camera and the Pencil of the Heliographic Art," by M. A. Root (1864).

around the turn of the century (1800-1801). Let us also consider Fox Talbot, whose original true photographs made before Daguerre's official date of 1839 are still in existence. These were real photographs, positive prints made from negatives. But no emulsion was used. The original negatives were made upon "salted" paper. Later, when photography became common, glass plates were coated with albumen or collodion, as the case might be, and sensitized by immersion in a solution of silver. The process was tricky because the plate had to be removed from the solution, placed in a plateholder, and exposed immediately. Should even a corner become dry, the plate was ruined. There were still other complications in those days. Projection paper was unknown; it was necessary, therefore, to use glass plates the full size of the print to be made.

You will wonder what equipment was necessary. We know quite well because there were amateur journals then just as there are today. One amateur of about 1865 was quite jubilant because he had worked out an outfit which could be carried by a strong man, or at worst "a man and a small boy," thus doing away with the necessity of using a pushcart or "perambulator" for the transport of equipment. Yes, "dark tents" of black cloth were actually set up at the site of the exposure as a part of the laborious routine of picture making.

The same periodical reviewed the "new" dry plates, but it was said that the quality was unsatisfactory and that because of their extremely slow speed it was probable that these plates would never come into general use. And in those days slow meant S-L-O-W!

But it was really the emulsion which ushered in the modern age of photography, and this is the factor to which we must devote some attention before considering the negative.

The Modern Emulsion.

Before the emulsion, the sensitive surface was simply a solution of silver salts spread over a medium which served to hold it. The emulsion, on the contrary, is a complex mixture—tiny grains of silver bromide formed in the gelatin matrix—and the whole mixture inherently sensitive from the moment it was made. It is often said that gelatin was used because it was the only vehicle of its kind known in the early days, but it must be remembered that both albumen and collodion were used before the invention of the emulsion-coated plate. Many vehicles were tried, including isinglass and both animal and vegetable glues. It was found that gelatin was suitable, not only because of its characteristic reaction with water, but a gelatin emulsion was decidedly more sensitive than those made with other supporting media.

In the first place, raw silver bromide made in direct solution and then submitted to a developer will be reduced no matter whether or not it has been exposed to light. The gelatin therefore acts as a restrainer, the action doubtless being a physical one in a measure. However, the increased sensitivity of the gelatin emulsion over others has been found to be due to the natural presence in gelatin of a substance called gelatin-X. According to Neblette², this is analogous to allyl mustard oil, and is an allyl isothiocyanate ($C_3H_5.NCS$). Its presence in gelatin in concentrations of one to four parts per million is sufficient to impart the increased sensitivity recognized in gelatin emulsions.

Even when it was found that the basic gelatino-bromide emulsion was more sensitive than other colloid-bromide emulsions, the emulsion was far from being perfect. In fact it was but little better than useless; the degree to which it has been perfected is one

* "Photography, Principles and Practice," by C. B. Neblette, F.R.P.S.

of the modern miracles of scientific industry. The original emulsion, and indeed the basic emulsion of today, is a suspension of silver bromide in gelatin. There are relatively small amounts of other ingredients, including silver iodide, but the silver bromide is the major constituent.

In considering the reactions of silver salts we must avoid the common error of thinking of the photographic reaction as a reaction to "light," for we must, to be consistent, restrict the term "light" to visual luminosity. It is a grave error to speak of invisible light, or black light, or ultraviolet light or infrared light. These are not varieties of light but of radiation. Such a distinction might be hair-splitting if the subject of discussion were radiation itself, but when discussing photography the distinction is of paramount importance.

To make this perfectly plain, suppose we make use of a simple illustration. If a sheet of paper is stretched tightly over a frame we might stick a finger through it, shoot an arrow through it, or shoot a bullet through it. All three would make holes, but that would not mean that fingers, arrows, and bullets are identical. Moreover, we should not be justified in speaking of the hole in the paper as either a finger, an arrow, or a bullet. The hole is simply the effect of the passage of one or the other of the three objects. In the same way, "light," analogous to the hole, is not anything of itself; it is simply the effect of radiation falling upon the eye. Therefore, while the emulsion is definitely affected by radiation it is not, speaking accurately, affected by "light."

Why is this important? Because most materials in nature respond definitely to radiation. X-rays and ultraviolet will cause some substances to fluoresce; infrared causes objects to become warm; radio waves are transformed into sound waves by the radio set, and so on. The illustration could be carried further to

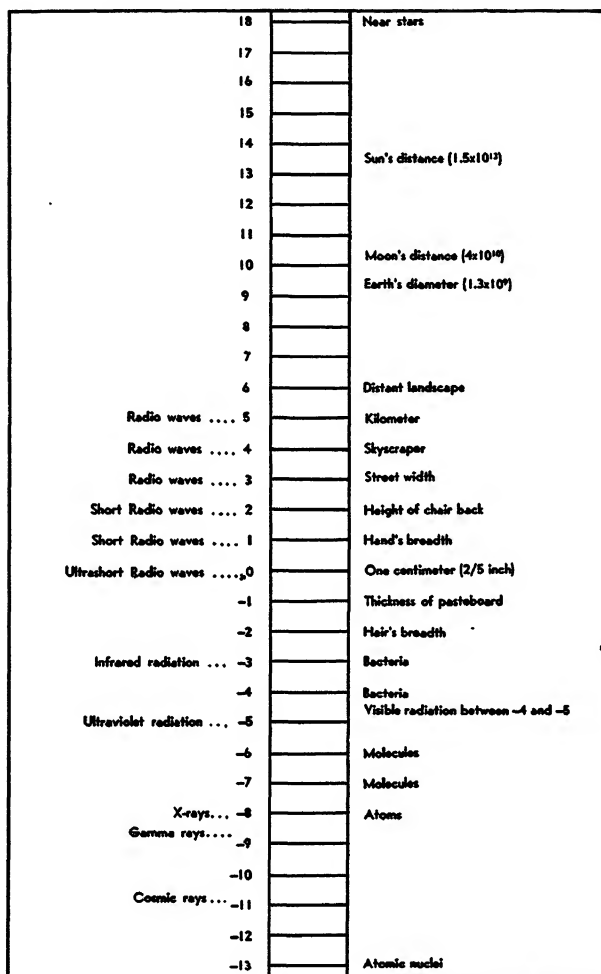
show that no matter what the specific radiation, something reacts to it. Silver bromide exists under considerable strain, and radiation of a specific type will produce an incipient breakdown of the compound which can be carried through to completion by the action of definite chemicals.

It so happens that the specific radiation which affects the emulsion in this way overlaps the specific radiation which produces the sensation of light in our eyes. The photographic reaction is naturally a reaction of the ultraviolet, and the fact that the specific causative radiation includes a slight amount of the high visible blue-violet was solely responsible for the discovery of photography years ago instead of recently. Thus the original emulsion, like the non-emulsified sensitive coatings, was sensitive only to blue-violet, and the plates could be safely processed in the orange-yellow light which is now sometimes used for bromide paper manipulation.

Radiation Spectrum.

Before going ahead with a discussion of the controlled alteration of the emulsion reaction, the relation of photography to the **great spectrum of radiation** should be made plain. It would be impossible to present a graphic representation of the great spectrum in linear form, because at one extremity we have radio waves whose length may exceed ten miles, while at the other we have cosmic rays so minute that their actual wavelength is a matter of argument among scientists. The radiation which produces light lies midway between the two, and an average wavelength of visual radiation is $1/50,000$ inch.

By devising a scale in which each division represents **ten times** the preceding one, the great spectrum can be presented plainly (Fig. 1). It must simply be



(Adapted from Bragg.)

Fig. 1. The Great Spectrum. Notations, right, give a graphic idea of actual wavelength size.

remembered that while the ordinary scale of five steps would represent values of 1, 2, 3, 4, 5; the same five steps in this scale would have values of 1, 10, 100, 1,000 and 10,000. On this scale the zero point is 1 centimeter (about $\frac{2}{5}$ of an inch). Each division above zero is ten times as great as the preceding one. Thus, the ascending scale is 1 centimeter, 1 decimeter, 1 me-

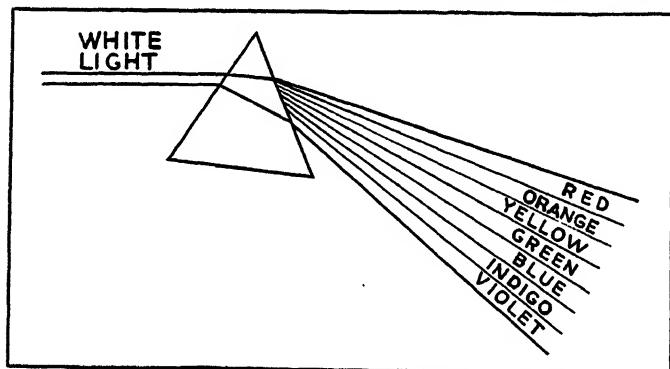


Fig. 2. White light dispersed into its spectral hues by a prism.

ter, 10 meters, 100 meters, etc. The descending scale is the same, except that each division below zero is one-tenth that of the preceding. Thus the descending scale is 1 centimeter, 1 millimeter, $\frac{1}{10}$ mm, $\frac{1}{100}$ mm, $\frac{1}{1000}$ mm (1 micron), $\frac{1}{10}$ micron, $\frac{1}{100}$ micron, 1 millimicron, 1 Angstrom, and so forth. On the left of the scale are shown the principal bands of radiation, except in the case of the range of visible light, which is noted on the right to prevent crowding the ultra-violet and infrared. Ultraviolet ranges upward, merging with X-rays, while infrared ranges from 10^{-4} to about 10^{-3} where it merges with Hertizian radiation.

Everyone has seen a rainbow, and many have witnessed the spectrum formed by a glass prism (Fig. 2).

And everyone is familiar with the seven colors into which white light is divided—red, orange, yellow, green, blue, indigo, and violet. Considered photographically, however, the spectrum is divided into three major divisions—blue-violet, green, and red-orange (referred to simply as blue, green, and red). The position of visible light is shown in Fig. 1 simply as a division line of the great spectrum, but as we shall be concerned with it, a separate illustration (Fig. 3) shows it in detail. The visible spectrum, more commonly known as the “rainbow band,” is the colored band which is seen when white light is separated into its component parts. It will be noticed (Fig. 3) that the visual spectrum has been extended into the adjacent ultraviolet and infrared bands. As both these are photographically active when modern emulsions are used, they will be discussed with the visual spectrum.

It must be understood that all radiation, no matter what its position in the great spectrum, is identical except for two interdependent characteristics, **wavelength** and **frequency**. Inasmuch as the velocity is constant, some 186,000 miles per second, it is obvious

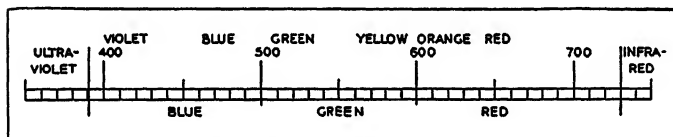


Fig. 3. The visible spectrum, showing three major divisions.

that when wavelength is shortened, frequency must be increased. So radio waves, heat, visible light, ultraviolet, X-rays, cosmic rays, and all radiation forms are merely effects produced by the same radiation in different wavelengths and frequencies; and it is quite probable that the frequency is the important factor with wavelength an incidental accompaniment. Radia-

tion may or may not be perceived by our physical senses. We recognize infrared by its heat and ultraviolet because it produces sunburn, but only in the visible spectrum do we find any radiation to which we respond specifically.

Following radiation up the scale of frequency, we know that if an iron rod is heated we can feel the heat radiated from it. If it gets hotter it begins to glow with a dull red color. That marks the division between infrared and visible light. The hotter the iron gets the faster become the frequencies of radiation it gives off. It grows orange, then yellow, then blue-white, and if heated by the passage of an electric current it next begins to radiate an abundance of ultraviolet.

So we see that the rainbow colors are simply indices of radiation frequency. Nor are the limits of visibility at all fixed, for some persons can see deep red or pale violet where others see only blackness, indicating a variation of visual limits among different individuals. Just so with the photographic emulsion.

Because the frequencies are given in such large numbers, the corresponding wavelength is used for measurement. There are two different units used in measuring visible light, the millimicron and the **Angstrom**. As there are ten Angstroms to the millimicron, the difference in measurement is merely that of adding or dropping a zero from the figure. To make the point more graphic, it may be well to add that in round numbers it would require two hundred and fifty million Angstroms to equal one inch. The limits of visual light are usually given as 380 and 750 millimicrons (3800 and 7500 Angstroms), and these limits are close enough for all practical purposes.

The photographic emulsion in which we are interested has but a single function, that of breaking down to liberate bromine and deposit a grain of opaque

metallic silver where there was a translucent grain of silver bromide. This breakdown may be produced by one of several agencies. Various chemical fumes including household gas will do it, excessive warm dampness will do it, simple physical pressure will result in a mark, but all of these agencies we wish to avoid.

The breakdown which we want is that provided when specific radiation falls upon the sensitive surface. We want to limit the reaction to specific radiation, and to exclude the action of such radiation as X-rays and ultraviolet, both of which affect the emulsion readily. X-rays are not a serious source of danger, as most of us live and work far enough from X-ray generators to be safe. Fortunately, although the emulsion is highly sensitive to ultraviolet, the materials of which our cameras are made exclude these rays, while the glass used in the lenses permits only an insignificant amount of ultraviolet to pass.

Color-Sensitivity of the Emulsion.

As the emulsion is most sensitive to ultraviolet, it is natural to assume that the visible light which will affect the emulsion most strongly is the high violet adjacent to the ultraviolet. This is true. So we have in the emulsion a chemical compound which is sufficiently unstable to break down under the impact of any one of several groups of radiation, the most important of which is that high violet region immediately adjacent to the ultraviolet.

This is a far different emulsion from the one which we use in our cameras today, but the difference lies, not in basic composition, but in the use of accessory ingredients which act upon the light in such a way that the longer wavelengths of green, yellow, orange, and red will also produce the desired incipient break-

down. These accessories are dyes which are mixed with the emulsion.

For us, the principal interest lies in the fact that through the use of dyes, the emulsion may be made to respond to colors to which it ordinarily would be inert or "blind." The accompanying curves (Fig. 4) show the relation between visibility of the average human eye and the sensitivities of five types of emulsions. The untreated emulsion, known as **color-blind** and typified by positive emulsions, lantern plates, process films, and so forth, is generally sensitive only to the blue and violet. This means that the photograph will show blue and violet as white and other colors as dark gray or black. It must be remembered, when such statements are made, that pure colors found in full white light are meant. In actuality, shadows revealing modeling will be reproduced, but even then the general fact holds true.

An emulsion which has been treated with dyes to extend its sensitivity to include green is known as **orthochromatic**, a misnomer remaining from the days when the increase in color response was considered so wonderful that the name "right color" was bestowed upon the emulsion regardless of its blindness to red. When the emulsion is so treated that it responds to all visible colors, it is known as **panchromatic**, meaning "all colors," a name probably better suited than the already usurped "orthochromatic." The emulsion to which that name should be given—that is, one which reacts to all colors, and to a degree similar to that of visual sensitivity—is known as the **orthopanchromatic** emulsion.

It must be borne in mind that the term "panchromatic" simply indicates that the emulsion is sensitive to red as well as to the other colors. This is just like saying that a man is a soldier without indicating his rank. The panchromatic emulsions vary widely both

in the matter of speed and in their specific color reactions. There has been some attempt to divide these emulsions into three types called A, B, and C. This subclassification is better than none, but it must be remembered that among the various brands of emulsions and among the various special emulsions, such a grouping must indicate arbitrary boundary lines

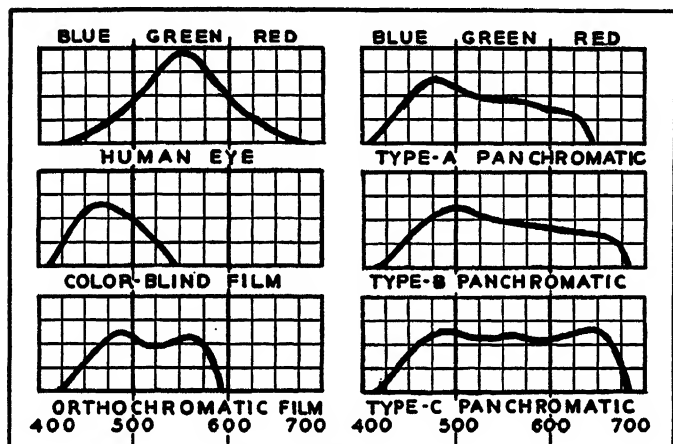


Fig. 4. Series of spectral curves showing the color sensitivity of five types of emulsions compared to that of the human eye.

which are characterized more by being overlapped than by any sharp distinction. Many emulsions are midway—perhaps more than adhere to the true classification.

A more accurate indication of the nature of these three classes is found in the names panchromatic (A), orthopanchromatic (B), and hyperpanchromatic (C). The type A is the direct descendant of the original panchromatic emulsion, somewhat sensitive to red but far

more sensitive to blue. It requires a filter to produce a result even resembling the panchromatic result.

Orthopanchromatic (or type B) has an almost uniform sensitivity to all colors, and having a comparatively high green sensitivity it most closely approaches the reaction of the average human eye. It does not require the use of a filter, but naturally reacts well when a filter is used. It is the most nearly perfect emulsion we have in point of color response.

Type C is the high-red-sensitive panchromatic made for one purpose, to give the utmost possible speed with incandescent light. It requires a green filter for normal reproduction because it combines the normal high blue sensitivity with an abnormally high red sensitivity, and for ortho results both red and blue must be suppressed to some extent. When the green filter (which is classed with the "yellow" group) is too heavy, the best procedure is to use a sky blue one to retard the red. Emulsions may fall anywhere within the range of all three, but any panchromatic film which has an unusually high sensitivity for incandescent light may be regarded as of type C, while most normal pan films of today can be correctly placed in type B.

Coated plates and films which are naturally color-blind can be sensitized to color by the use of dyes. Solutions of Pinaflavol and Sensitol red may be made—about four parts dye to a million parts of water. The films are soaked in cold water until the emulsion is thoroughly wetted, and then bathed in the two dye solutions, successively, or in a mixture, for about two hours at about 50° F. The process is not recommended as routine, but as an experiment it will prove interesting. The use of dyes to extend the accidental overlap of the two regions of photo and visual sensitivity in the blue has made it possible to use the photographic process to reproduce material objects with a fair approach to monochromatic accuracy in



Showing how the three popular types of films render color in black-and-white. Above, the bouquet of flowers was photographed on color-blind film; top, right, same shot made on an orthochromatic film; right, another shot of the same bouquet made on panchromatic film.



color value. Naturally without such extension, natural color photography would not be possible at all.

It must be kept in mind at all times that the names given are only approximate. Color-blind films may be used to reproduce yellows, and many orthochromatic emulsions will give quite satisfactory results when used with a light red filter. The names given indicate the relative sensitivities, and an exposure which would satisfactorily record other colors on an orthochromatic emulsion would still leave red objects extremely dark.

The subject of color sensitivity has purposely been introduced before a discussion of the inherent characteristics of the emulsion simply to clarify the issue. The basic emulsion is largely the same, no matter what its sensitization, and that is the emulsion which we shall now investigate.

Nature of the Emulsion.

As is generally stated, the photographic emulsion consists of a mixture of gelatin and silver bromide coated upon a suitable base such as glass, celluloid, or paper. There are many varieties of emulsions, but a typical emulsion has these chief ingredients in approximately the percentages shown:

Water	10
Gelatin	55
Silver bromide	33
Silver iodide	2
Silver chloride	trace

Silver bromide is found in the emulsion in flat crystals of triangular or hexagonal shape with a thickness about $1/10$ their diameter, although this proportion varies widely. The size of the crystals usually varies from 0.0002 to 0.004 millimeters, depending upon the character of the emulsion. It must be remembered that in any given emulsion there is a wide variation in

grain size, and these measurements are only the average. In a typical high-speed emulsion, the majority of grains are of the larger dimension, with approximately a half billion grains per square centimeter.

The emulsion itself is thin, the average ranging from 0.025 to 0.04 millimeter in thickness. Although this means that six or seven hundred emulsions could be piled up and not equal an inch of thickness, the emulsion must never be regarded as a mere surface. It is a layer of finite depth upon the surface of the support, a layer built up of many strata. It can be seen that with grains of the largest size, that is 0.004 mm, the emulsion is thick enough for ten such grains to lie edgewise in the thickness of the emulsion. As a matter of fact, considering the accidental orientation of the grains and their varying size, it will be convenient for purposes of description to consider the emulsion as having twenty such definite strata (Fig. 5), although in the actual emulsion there is no stratified structure.

The most accurate magnified picture of the emulsion which comes to mind is a flat pie pan filled with gelatin dessert into which is mixed a quantity of chopped nuts. This presents a picture true in every respect of the developed emulsion, because in the process of development the definitely shaped grains gather into irregular clumps of various sizes, not at all dissimilar to broken nut meats.

The next question is, "What happens when the emulsion is exposed to light?" It has not as yet been definitely answered. Many theories have been proposed; some facts are known, and from the mixture of fact and theory we have a fair picture of what may be the truth. The silver bromide grain has a definite lattice structure, as have all crystals. This lattice is formed of atoms of silver and of bromine; but the combination is rather unstable. That is, it takes very

little stimulus to cause the silver and the bromine to part company. Nor is it necessary for complete grain to break down. Some of the silver atoms may combine and form a sub-microscopic speck of silver within the grain. This actually does happen, but there is some division of opinion as to whether these specks are present before exposure or whether they have their origin during exposure. There is also some question as to whether the specks are metallic silver or silver sulfide, although the general opinion seems to favor the metallic silver theory.

Thus we have a silver-bromine compound so unstable that it may be partially dissociated without a complete separation taking place. This compound is exposed to the impact of light. Again we have various theories, but the favored one is that of a physical impact of the light unit or photon upon the emulsion, just like a bullet being fired into a shelf of fragile pottery vases. This physical impact either produces the initial silver speck, or using that as a focus, produces a similar and greater breaking down of the compound. We now have a condition in which many of our vases are cracked by impact but still hold their shape until touched, when they crumble. Just so we have the silver-bromine compound still holding its general form, but ready at the touch of a reducer (developing solution) to break down into its component elements.

There is a definite relationship between the amount of light per unit area necessary to produce this crack-up, usually stated as so many units of energy per square micron grain area. This is not a fixed factor by any means, as some grains are more stable than others. This is important because, except for the formation of the sub-microscopic sensitive speck, it is not possible to break down a portion of the grain. Once the disintegration has started the entire grain gives up its bromine and becomes silver. This action is also

imparted to any other unexposed (or exposed) grain which is actually in physical contact with the grain which breaks down.

It is obvious that with a half billion grains in an area considerably smaller than a dime, many grains will touch and some of them even form long, crooked chains. This does happen, and it is the breakdown of these connected grains which is responsible for graininess, loss of resolving power, and other faults of the negative characterized by the absence of a knife-sharp border around any area. Therefore, just as it is the intention of the emulsion maker to have each individual grain coated with a protective layer of gelatin, it is our intention in processing to make use of a developer which shall develop every grain which has been exposed to light, but one which shall not destroy the delicate insulating wall of gelatin and cause the reduction of grains which have not been exposed. We shall see that this ideal cannot be fully attained in either respect, but we can approach it nearly enough to enable us to obtain good quality in the resulting negatives.

Naturally the question arises as to how this emulsion is formed. At the risk of some repetition, now that we have a general picture of the basic emulsion in mind, we shall see just how the emulsion is made. The ingredients include pure silver nitrate, potassium bromide, potassium iodide, and gelatin. The bromide and iodide are thoroughly mixed into the gelatin, the salts being in solution at the time. To this solution, which is kept warm and continuously agitated, the silver nitrate solution is added slowly. The nitrate solution may be neutral but is usually slightly alkaline, ammonia being used to obtain the desired alkalinity. The rate of mixing and relative amounts affect the final result. Perhaps more than any other widely used commercial product, the emulsion varies according to

the treatment it receives in manufacture. For example, if the metallic salt solutions are added slowly and in the form of weak solutions, the resulting emulsion will tend toward finegrain results and low sensitivity characteristics, while if concentrated solutions are added rapidly the result tends to be coarser grained and faster.

After the mixing, the emulsion is ripened by cooking it at a low temperature for several hours. The temperature during this step is controlled accurately, and is usually in the neighborhood of 140° F. This process makes the emulsion more sensitive, but if allowed to continue produces grains which will develop without the usual exposure to light. In short, this produces chemical fog, of which a trace at least is expected in all normal negatives. When the cooking step is complete, a solution of heavy gelatin is added to make the whole emulsion set more readily.

When the gelatin has set into a firm jelly, it is forced through a press which is not unlike a food chopper, but instead of a revolving blade, the end of the press is a perforated sheet through which the gelatin is forced, taking on the form of long shreds, not unlike spaghetti. These shreds are washed thoroughly in repeated changes of water to remove the soluble salts remaining in the emulsion—the bromide, nitrates, and ammonia if any was used. After washing, the shredded emulsion is kept in cold storage until wanted for use.

When coating is to be done, the shredded emulsion is removed from its ice storage and drained to remove any collected moisture. It is then melted over a water bath (as dessert gelatin is cooked in a double boiler), and at this stage various additions are made. Usually alum is added so that the emulsion will become comparatively hard when dry and therefore withstand handling. At this stage a small part of potassium bromide also is added for exactly the same purpose it serves

in the developer, namely, to hold back chemical fog and to produce a better negative. At this stage are added the sensitizing dyes, and finally a wetting agent of some kind which will cause the mixture to flow over the surface of the support more readily and more uniformly.

The base is first given a coating of insensitive material with which the emulsion can bond and so cling firmly to the support. The first rollfilm was not made simply by coating a piece of celluloid with emulsion. That was tried years before the film became a success. The real invention of the rollfilm was made when the use of the substratum was invented.

The melted emulsion is flowed over the base and then set, usually by the use of some type of refrigeration. It is then further dried and finally cut into the required size and packed for use. This, then, is the nature and method of manufacture of the sensitive materials which we shall use for making the negative. Thus far we have dealt with an imaginary thing which we have called an "average" emulsion. In fact there are many, many different kinds of emulsions, but those which we shall use in producing negatives resemble our "average" closely enough for us to continue to use this dummy emulsion for purposes of demonstration.

Response of Emulsion to Light.

Assuming an emulsion is to be exposed to light, what happens? To explain this we shall have to consider the problem from different points of view. First let us assume that the emulsion (coated upon a smooth support) is simply exposed to light for an undetermined period. The bombardment of light affects the grains of silver bromide as has already been explained, making them unstable. But this action is not instantaneous. Just as we must consider lengths measured

in millionths of an inch as finite measurements of length, we must also consider microseconds as finite measurements of time.

The bombardment first strikes those grains near the surface and then, progressively, the grains which lie at lower and lower depths, until the entire emulsion has been penetrated. Thereafter the light will pass on until it strikes the supporting surface behind the

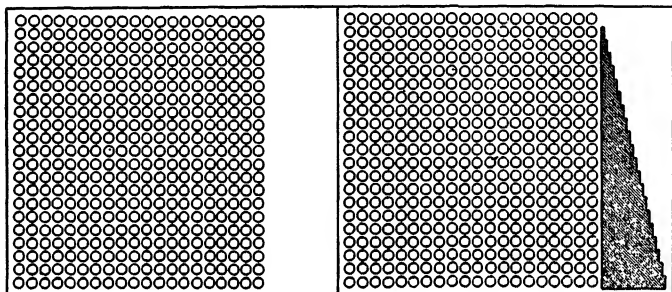


Fig. 5. Representing 21 strata in an emulsion, each with 20 equal units of silver bromide.

Fig. 6. Light-absorbing wedge is placed over this emulsion to regulate exposure (see text).

film, from which it is partially reflected. It will again pass through the emulsion, this time starting at the bottom layer and working upward until it passes out again on the same side it entered. If this emulsion is then submitted to the action of the developing solution, almost all the grains of silver bromide will be transformed into microscopic grains of metallic silver, and the thin tissue of emulsion will become practically opaque to light.

The second passage following reflection will produce a false image known as *halation*. This is to be avoided if possible. For this reason, most sensitive materials intended for negative production have a coating on their backs or incorporated within their

structure which will absorb any light falling on it. This is known as an **antihalation** stratum. Originally such plates were called "backed" plates, but later, particularly with the almost universal introduction of films, the treated product has been called simply "antihalo."

Notice that almost all the grains will be altered. In fact there are some grains which are affected by light only with difficulty, and still others which are so refractory that many times the light required to bombard the greater part of the mass completely will fail to alter them. Thus we have a certain residue which has no practical value. However, these grains are so few that they do not seriously affect the final result.

If it is true that the light passes through the emulsion progressively, it should be possible to regulate the exposure so that the light can be stopped when it has only half penetrated the emulsion, or to limit it to any other portion of the whole which may be desired. This can be done. In fact it is exactly this control which makes possible the photographic process. In considering the regulation of light we will ignore the factors of light intensity and time of action for the moment, and concern ourselves with the product of these two factors—namely, the quantity or volume of light. It is true that we regulate the volume through dual controls of time and intensity, but as these have a variable relation we shall consider imaginary "units" of light of constant volume-per-unit.

As we have taken a twenty-strata emulsion for purposes of discussion (Fig. 5), we shall also assume twenty units of light to be available. We shall also assume that one unit of light has just sufficient volume to react with the topmost layer of sensitive grains. Having twenty units of light available, we shall also assume that we have a translucent tablet (similar to a negative) with twenty strips of varying density (Fig.

6). The first strip will absorb all twenty units of light; in other words it is opaque. The second will absorb nineteen units, the next eighteen and so on until the last one absorbs just one unit of light. This tablet is placed over the sensitive emulsion so that a narrow band of the emulsion is exposed to the action of light which passes the end of the tablet and is therefore full strength. This gives us twenty-one different exposures on the emulsion.

Where all the light is absorbed, there will be no action upon the negative. In the next strip where there is a loss of nineteen units, one unit will pass through and its energy be expended in reacting with the topmost layer of grains, and so on. Thus, throughout the emulsion we have the light penetrating deeper and deeper (Fig. 7), until the entire thickness of the emulsion is affected.

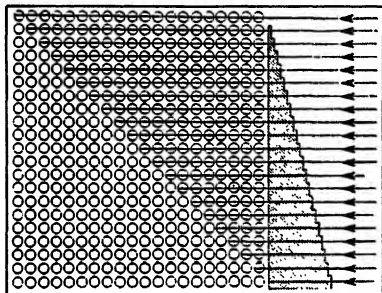
This is indicative of what actually happens when the emulsion is exposed in a camera. In fact there are many times in laboratory and experimental work when the emulsion is actually exposed under such a tablet—for example, when sensitivity measurements are being made with the Eder-Hecht densitometric tablet.* This tablet is a small film—a test negative, in fact—containing narrow bands of increasing density so that one end of the film is transparent while the other is practically opaque. At the sides of this tablet there are two sets of three bands which cross the others at right angles. These sets are covered with tri-color filters so that a single exposure will give not only a numerical evaluation of the sensitivity of the emulsion under test, but it will also give a similar evaluation of the sensitivity of the film to each of the three principal spectral bands. Inasmuch as these three bands, (the blue-violet, green, and red-orange) correspond to the limit sensitivity of the three major types

* This device will be more fully described in Chapter IX.

of emulsion, the Eder-Hecht tablet provides information about three important factors: the overall sensitivity of the emulsion; its color-response type, whether color-blind, orthochromatic, or panchromatic; and the relative sensitivity to the spectral bands.

Such a tablet is an efficient sensitometer, and for the usual run of amateur work it will satisfactorily replace the far more costly disk sensitometer. Although

Fig. 7. The emulsion is exposed to light of 20 units strength. Lines from arrows represent amount of penetration.



not now available in the original form, it is said that an improved tablet of domestic make will soon be available.

It must be remembered that when the light falls upon the emulsion the change which takes place is not visible. True, if the action continues through long exposure to light there will gradually take place a complete breakdown, and the emulsion slowly darkens; but we are not concerned with this at the present time. The brief exposure we have given the emulsion (Fig. 7) only serves to produce the incipient breakdown we have already described, but there are two characteristics of this preliminary reaction which we must keep in mind.

Although invisible, the emulsion has reacted proportionately according to the intensities of the original exposure (Fig. 8), and there is a physical image in the

emulsion, even though it is not visible. This is the **latent image**. The second point is that after exposure, the "innoculation," if we may be permitted the term, does not spread, but remains confined to the original image. There is one change which takes place, namely, the further breakdown of the sensitive material, so that for a short time after exposure there is a growth in intensity of the image analogous to an increase in the original exposure. This is sometimes spoken of as a gain in sensitivity after exposure; but it seems improbable that there would be a gain in sensitivity after the stimulus to which the emulsion is sensitive has passed.

This after-growth is variable and is dependent upon atmospheric conditions. There are some places, particularly the deep tropics, where the latent image fades and it has been reliably reported that films exposed and left undeveloped for three or four days can be used again without the slightest trace of the first image's being apparent in the negative. Development is advised within two hours after exposure, and even when a decided overexposure is made. I have had no personal experience under such conditions, and pass on the information received firsthand from a reliable technician; but no guarantee is made as to the absolute accuracy of the report. It is known definitely, however, that such fading does take place, and that early development is recommended under these conditions.

We have already discussed the sensitivity specks which occur within the silver-bromide lattice. While these specks are said to be free atoms of metallic silver by some and silver sulfide by others, evidence indicates the silver theory is the more acceptable. Whichever may be the truth, after exposure we have an emulsion in which the silver bromide grains contain **development nuclei** which are probably nothing more than

sensitivity specks whose growth has been stimulated by light action. At any rate, we do know that the development of a grain consists of a silver growth from these centers and not from the grain surface upon which the developing solution first falls.

One thing which is of interest has already been mentioned in passing, namely, that when the developing solution acts upon a developing nucleus, the sur-

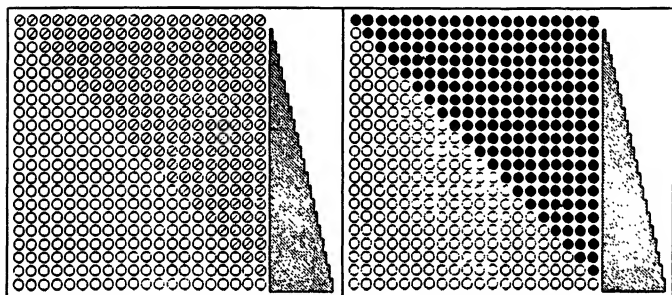


Fig. 8. Exposed silver halide units, ready to be developed, form invisible latent image.

Fig. 9. Units of latent image converted into metallic silver by the process of development.

rounding silver bromide gives up its bromine and becomes silver; then all bromide grains touching that silver are in turn reduced to silver, and the process continues until all the silver bromide in physical contact has been changed to silver, regardless of the space distribution of the developing nuclei. This accounts for the fact that an unexposed grain of silver bromide in actual contact with an exposed one will be developed just as though it had in fact been exposed.

Briefly, then, exposure to light produces internal changes in the silver-bromine relations which cause the reduction to metallic silver to occur under the stimulus of a chemical bath commonly called the **developer** (Fig. 9). This is a phase which will be discussed later.

We have already considered the differences in emulsions as regards their reaction to color. We have described the color-blind, ortho, and pan emulsions, and have noted that the extension of color sensitivity beyond the blue has been accomplished by the use of dyes. The exact action of the dye is still a matter of difference, but it seems certain that there must be an absorption of the dye by the silver bromide molecule. There have been arguments in favor of a fluorescent action, similar to the action of the intensifying screen in X-ray work; but this is hardly tenable because some excellent dyes do not fluoresce, some highly fluorescent dyes are not good sensitizers, and there is a total lack of accord between fluorescence and sensitization. On the contrary, the dye has some effect which is not, strictly speaking, a chemical one.

While guessing is popular, I will add my guess to the lot, just for good luck. There is an excellent basis for the fluorescence theory, and the lack of accord may well be due to the fact that the researchers have given too much importance to "visual" effects and have forgotten that there is not necessarily any direct connection between visual and photographic results.

Fluorescence is very closely akin to "heterodyning" in radio reception; that is, two different frequencies beating against one another will produce a third frequency different from both, and equal to either the sum or the difference of the originating frequencies. Fluorescence as commonly known is the production of visible light produced by the impact of invisible radiation upon various substances. There is no reason to doubt that there is an abundance of "invisible fluorescence." It is known that the visible effect may be of greater or less frequency than the stimulating radiation. Therefore, just as we have ultraviolet producing red, yellow, green, and blue fluorescence in the visible region, it is quite possible that visual red may produce

an ultraviolet fluorescence when striking a red-sensitizing dye, thus giving high red sensitivity.

But here again, if we accept such a theory as possible we must remember that we do not have any kaleidoscopic play of color, but just as in radio we have one frequency band to which the silver bromide grain is most sensitive—just as a glass goblet may be shattered by a high note from a violin—and we have heterodyning agencies which take other frequencies and change them to the critical one. The result is that we have a physical change taking place in response to a critical period of vibration, a phenomenon which is familiar to everyone. Remember how you used to make the piano “A” vibrate by sounding the same “A” on a violin, or even by leaning close to the strings and humming the same tone?

If this is true, it should also be true that harmonics of this critical frequency would have similar action. We find that many of the higher frequencies have strong photographic action, as in radium emanation, X-rays, and so forth; and we find a more or less periodical variation in the sensitivity of such reactions. When we consider that we have not a single critical frequency, but a band of frequencies located in the near ultraviolet and visible blue-violet, we have the conditions under which we might well predict the common photographic reactions, using nothing beyond elementary radio theory!

Also, if this is true, it should be possible to sensitize the emulsions to radiation frequencies beyond the visual range, in the direction opposite the ultraviolet. In short, if our efforts at sensitization stop with the visual band, then there is a direct connection between photographic effect and the visual one. On the contrary, if the sensitization covers the visual band and then continues over into the invisible, we have perfect evidence that we are working purely with fre-



Eastman Kodak Co.

Normal effect of radiation from visible spectrum on pan film.

quency, and that the coverage of the visual band is accidental, in one manner of speaking.

In actual practice sensitizing dyes or "heterodyning dyes" will sensitize the emulsion so that the sensitization falls short of the visual range, or the sensitization will fill the visual range and go on into the infrared to a greater or less distance. Moreover, the emulsion can be sensitized so that it is not sensitive to the green or red, but is highly sensitive to the infrared; not only this, but the frequency within the infrared to which the emulsion will have peak sensitivity may be chosen at will. Of course, as this does not include any actual change within the emulsion but is only a method of using the known laws of wave mechanics, the frequency to which the emulsion is inherently sensitive



Eastman Kodak Co.

Effect of infrared radiation on film sensitized to the infrared.

will not be changed. The emulsions sensitive to infrared, therefore, are still highly sensitive to blue and violet, but not to green or visual red. Thus, when making use of this type of film it is customary to remove the blue-violet frequencies from the light which falls upon the emulsion, leaving only the invisible infrared. This is done by a filter which appears perfectly transparent to the eye, and is orange or red in color. It is effective simply because its sole purpose is to remove the blue and violet. This point brings up the question of filters.

The subject of filters is too broad to be discussed thoroughly here. It is sufficient for our purposes to state that photographic color filters have just one function, to suppress certain groups of frequencies. Thus

the yellow filter suppresses the blue and violet frequencies; the yellow-green suppresses the blue, violet, and red; and so forth. The filter is simply what its name indicates: a device to filter out from the used light certain unwanted frequencies. And as frequencies are interpreted by our eyes as color, the general effect of the filter is translated into color differences.

There is one point which should interest the inquiring amateur: the emulsion is not inherently sensitive to red. The ordinary emulsion can be exposed and then developed in red light without the emulsion's being further affected. This same emulsion can be treated with a red-sensitizing dye, then exposed in a camera whose lens is covered with a red filter, and thus exposed to nothing but red light; an image is formed as readily as when white light was used in the first place.

In terms of mechanics, we have here a case in which a lattice is disarranged by vibration of frequency A, but is not in any way affected by frequency B. Then something is interspersed within the lattice and suddenly it becomes very sensitive to frequency B. Either of two things may have happened:

1. The new material introduced may be affected by the second frequency and then have transmitted its response to the lattice.

2. The newly introduced substance may have some property of absorbing frequency B and as a result emitting frequency A, to which the lattice is sensitive.

If we accept the first theory we must believe that the sensitizing dyes are themselves light-sensitive, otherwise the continued impact of light would bring about the characteristic reaction and bring it to its termination before the use of the dye. But if the second case is true, then the property of the foreign substance is not a reaction which starts, runs its term, and terminates, but a reaction which takes place as often as the stimulus is applied.

So here is the presentation. We shall not carry it further because it is not offered as proven fact, but simply as an hypothesis which may give food for thought to those interested.

Summary.

Thus far we have, at the risk of some repetition, tried to instill some familiarity with the nature of the gelatino-bromide emulsion and its reactions as applied to photography. The repetition has been necessitated by the desirability of developing the various factors in more or less parallel relationship. Now let us summarize the facts which have thus far been developed.

1. The gelatino-bromide emulsion is principally a physical suspension of silver bromide in a vehicle of gelatin.

2. Gelatin is physically desirable because of its physical factors of pellicle formation, transparency, and its habit of swelling when moistened, only to dry back to its original shape when the water is removed.

3. Gelatin produces a more sensitive emulsion than other colloids, principally because of the presence of natural oil of mustard.

4. There is a spontaneous, incipient breakdown of the silver bromide with the result that "sensitivity specks" of silver (silver sulfide) are deposited within the molecule.

5. There are small percentages of silver iodide present in the emulsion and traces of silver chloride which result from the presence of chlorine in the water and as an impurity in the other chemicals.

6. The impact of light upon the emulsion increases the tendency of the exposed grain to break down with a probable increase in the mass of the sensitivity speck.

7. A single grain cannot be partially developed. If

any part of the grain is exposed the entire grain develops. Any unexposed grain in physical contact with an exposed one will also be developed.

8. Photographic differentiation is obtained through the exposure of a greater or lesser number of grains per unit area.

9. The natural emulsion is inherently sensitive to ultraviolet, visible violet, and blue. Sensitivity to longer wavelengths is imparted by the use of sensitizing dyes which probably act through a quality of the general character of fluorescence.

10. Changes after exposure are normally toward greater image density, but in some cases the reverse may be true.

II

DEVELOPMENT OF THE IMAGE

II

Development of the Image

THE image obtained by exposure is, as has been stated, invisible. To produce the visible and printable image, the exposed grains must be reduced to their silver state. This is done by the use of a class of chemicals known as reducers. It is of the greatest importance that these reducers or developing agents should never be confused with the silver-dissolving chemicals used to reduce the density of the developed negative. It is unfortunate that the chemical term and the physical one should be identical, but as a rule the way in which the word is used will serve to identify the "reducer" which is under discussion.

Not all reducing agents are suitable for photographic development. Some of them will not develop the image at all; others are so active that they reduce all the grains of the emulsion with no regard to any preceding exposure to light. Obviously, both of these groups are useless. There are still others which tend too much toward one or the other of these two groups

to have any practical value. This leaves us a small group of agents which are suitable for developing the image. These include such familiar agents as metol, hydroquinone, amidol, glycin, and others.

It might be said that those reducers which develop regardless of exposure have great developing or reducing power, while those which will not develop at all have little reducing power. Instead of using just these terms, however, let us say that the very active developers have a high reduction potential while the weaker ones have a low reduction potential. Thus, when you meet these terms, remember that they can be simply (and not inaccurately) considered as referring to "powerful developers" and "weak developers." We do not use these latter terms because it is possible to make a strong developer using a low potential reducer, and conversely to make a weak developer from a high potential reducer. Ordinarily the terms "strong" and "weak" are limited to references regarding the concentration of solution.

You will remember that a statement was made to the effect that a certain "quantity" of light must fall upon a silver grain to make it developable. That is true; but how great or how small that quantity depends not upon the bromide alone, but also upon the developer to be used. High-potential developers will reduce grains which received so little light as to be unaffected by low-potential developers. This is to be expected when we consider that our chosen reducers are not a sharply isolated group, but start near the limit of those which will not develop at all and range upward next to those which will reduce regardless of exposure. Our useful developers, therefore, will all stand midway with some tending toward one extreme, others toward the other. In consequence we should expect some characteristic action just like that which was stated at the beginning of this paragraph.

You often hear the statement made, "You cannot develop an image which has not been impressed by light." Now that is very true if we interpret the word "light" broadly enough and if we specify a recognizable image of a real object; but there is the corollary not so widely known, "With a high-potential developer you can develop an image which is too weak to be developed by a low-potential one." Here we have the first step in that strong bond which constantly reappears between exposure and development. So close is this bond that it is impossible to make any statement about either (except the broadest generalities) unless the statement includes the relationship of the other factor. Thus, any correct exposure can only be correct relative to a given development. Conversely, any given development is correct only in relation to the given exposure. The attempt to create two systems of independent exposure and development has produced a condition of chaos in the ranks of amateur photographers. The only thing which can be done in this respect is to assume some optimum exposure and then give the related development. Naturally the amateur assumes that this exhausts the possibilities of both, when nothing could be much further from the truth.

We have assumed that actual physical impact of light produces the initial breakdown of the bromide. We know as a matter of experimental fact that an exposed emulsion weighs more than an unexposed one, the difference being assumed to represent the weight of the light absorbed. But we cannot imagine any disturbance taking place in the developing solution which would repeat the impact to a magnified degree. No, the development is simply a matter of amplification of the latent image; although it is true that the degree of differential amplification among various densities does lie within our control.

The chemicals of the developer penetrate the gela-

tin. As the developer solvent is water, the gelatin will swell to a marked extent, but upon later drying it will return to its original position. **This is of the utmost importance.** It permits easy penetration of the solution without permitting any distortion of the image through regional displacement of parts of the gelatin.

Having penetrated the gelatin, the solution dissolves the silver bromide, and the solution **within the gelatin** becomes a fully saturated solution of silver bromide. When this happens, the silver is deposited upon the sensitivity specks, and the process continues until complete deposition has taken place. Students of elementary chemistry will remember that it is possible to make saturated solutions of many salts. These will remain liquid until a crystal of the same salt is introduced; when that is done there is a rapid crystallization of the salt. They also know that when the solution is supersaturated (as when a hot saturated solution is allowed to cool) the introduction of the single crystal will sometimes result in the instant crystallization of the entire bulk of solution.

Here we see the actual role played by the sensitivity specks in the film emulsion. The solution of bromide will not give up its silver in the absence of some nucleus upon which to deposit it. This not only explains why the nuclei are necessary, but it also explains why development proceeds from the sensitivity speck outward. It also gives us a pretty good idea as to why the developed grains do not conform identically to the pre-existing grains of silver bromide.

Naturally, solution starts as soon as the developer penetrates the gelatin. Inasmuch as it penetrates the upper strata of gelatin first, it may logically be assumed that grains in the top layer may be almost full grown before some of those in the bottom layer have reached full solution. Thus, development is a progressive reaction from the uppermost layer down

through the emulsion, and in each "stratum" it is a progressive reaction from penetration, through solution, to deposition of the metallic silver.

This process of development hints at electrolysis, and it may be noticed that when substituting one alkali for another in the developing bath, the ratio of substitution is based neither upon chemical composition nor upon the heat developed in neutralizing them. It is based on the production of solutions wherein the same unit resistance will be formed; moreover, experiment shows that the rate of development in a bath is proportional to the electric resistance of the solution. This may be contested, as the tendency of modern science to reduce everything to electrical terms is considered by some to be carried to an excessive degree. The fact, however, was recorded by Arthur von Hübl in 1901.

Suppose we consider each individual grain as a unit in which electrolysis is taking place. If the electrolysis is continued for very long there will be an accumulation of oxygen at the anode which will insulate it, and further electrolysis will not occur. However, if some chemical is present which will combine with the oxygen (i.e., a reducer), this oxygen will be removed and the metallic silver can be deposited by electrolytic action. We already know that efficient developers are reducers, so it is reasonable to conclude that here is an hypothesis which is at least tenable.

So much for the generalities of development. Our next interest is in the direction of specific development as practiced in ordinary photographic darkrooms.

The Reducing Agent.

As has been stated, the actual developer is a reducer and ordinarily an organic compound of somewhat complex type. Among the simpler metal-organic

compounds is **ferrous oxalate**, once a favorite developer but now rarely used. Among other older developers are **aduro** (chlorhydroquinone), **azol**, **diogen**, **dianol**, **eikonogen**, **imogen sulfite**, **kachin**, **ortol**, and **quinamet**. It is doubtful if any of these except the first could be found on the shelves of a modern photo shop. It is more to the point if we give our attention to developers now commonly in use. In addition to the chemical characteristics of the various developers we shall note their relative developing potential.

Of the developers now in common use, no doubt **metol**, **hydroquinone**, and **pyrogallol** (pyro) exceed all others in popularity, with **paraphenylenediamine** and **glycin** next in their roles as finegrain developers, and **amidol** in sixth place as a special but universal agent.

Pyrogallol. Commonly known as **pyro**, and erroneously as "pyrogallic acid." 1-2-3 trihydroxybenzene, $C_6H_3(OH)_3$. Reduction potential, 16. This is one of the oldest developers, having been used as early as 1851. Pyro produces a metallic image accompanied by a stain which improves the printing quality and acts in some measure to mask graininess. Although disliked on account of its propensity to stain, it is probably the foremost developer available in the chemical group for the production of negatives of superb quality.

Metol. Commonly sold under this and other trade names (the name "metol" is itself a patented trade name), such as **Elon**, **Pictol**, **Satrapol**, **Veritol**, **Rhodol**, and so forth. **Paramethylaminophenol sulfate**. $C_6H_4(OH) \cdot (NH \cdot CH_3) \cdot \frac{1}{2}H_2SO_4$. Reduction potential, 20. Gives negatives full of detail but inclined to thinness; very rapid in action, and commonly used in conjunction with a slower acting developer.

Hydroquinone. 1-4 dihydroxybenzene. $C_6H_4(OH)_2$. Reduction potential, 1. A slow, clean-working developer, which loses its active quality at temperatures below 60° F. As its low potential prevents

it from affecting emulsion grains which have received weak light, this developer used alone is excellent for high contrast work, such as line copies. In ordinary work it is usually combined with metol to form a "universal" M-Q type of developer.

Paraphenylenediamine. 1-4 diamino benzene. $C_6H_4(NH_2)_2$, also used as the hydrochloride $(C_6H_4(NH_2)_2 \cdot 2HCl)$. Reduction potential, 0.4. Used alone it only partially develops each grain and does not provide sufficient contrast. Used with an alkali it is more energetic but does not produce sufficient shadow detail owing to its low potential. These defects are usually compensated for by adding another developing agent such as metol or glycin. Paraphenylenediamine is not a new developer, having been used since 1888, but recently it has come into vogue as a finegrain developer. There is some question as to the practical value of this agent inasmuch as the fine grain is obtained at the cost of shadow detail and other desirable qualities.

Glycin. Parahydroxyphenyl glycin, $C_6H_4(OH)(NH \cdot CH_2COOH)$. Reduction potential, 1.6. Glycin deserves more attention than has been given it. By itself it is a slow but satisfactory finegrain developer, producing good, clean negatives of excellent printing qualities. It is somewhat difficult to prepare, but a favorite among those who have learned to use it. Now restricted almost entirely to its role as one constituent of finegrain developers.

Amidol. 2-4 diaminophenol-di-hydrochloride, $C_6H_3(OH)(NH_2)_2 \cdot 2HCl$. Reduction potential, 30 to 40. Amidol is unique in that it will function without the presence of an alkali added to its solution. Not widely favored because of its poor keeping quality, it has high favor among its adherents who claim that its action is superlative. Used by many outstanding pictorialists for both negative and positive development. When

stale or even when made up with old sulfite, the image lacks brilliance. To get results from this excellent developer, fresh sulfite must be used, and the solution itself must be freshly mixed.

There are a few other developers which might be mentioned, but among them perhaps there is only one which has any real advantage. This is **paraminophenol** (paramidophenol), which is usually sold as the hydrochloride $C_6H_4(OH)(NH_2) \cdot HCl$. This is more commonly known by the trade name **Rodinal**, which is a concentrated solution to be diluted for use. Kodelon is the trade name for the oxalate of paraminophenol. Clerc³ credits J. Desalme with recommending the use of the tartrate so that concentrated solutions can be made without the use of a caustic alkali. Stock solutions of Rodinal and its imitations are made with caustic alkalis, although the alkaline carbonates are to be preferred. Because of the reactions which take place, the use of carbonates with this developer is limited to the preparation of solutions of working strength.

It is well known that a developing solution contains a small amount of the actual reducer as compared with the amounts of other chemicals used in the same solution. Each of these has a definite purpose, and the characteristics of the compounded developer can be profoundly changed by alterations in the proportions of these constituents and by changes in the concentration of the solution.

The developer has a certain function to perform; it must reduce all the silver bromide grains which have been exposed to light and not affect those which have not been so exposed. Actually, some grains which have not been exposed are developed, and some which have been exposed do not develop. Therefore, the practical developer is one which will closely approximate the ideal. To make such a solution, certain

³ "Photography: Theory and Practice," by L. P. Clerc.



Negatives developed in too contrasty a developer produce prints with burned-up highlights and no shadow detail on normal paper.

chemicals are added to the reducer. Ordinarily these accessory chemicals include an alkali which affects the gelatin so as to permit rapid and easy access of the solution throughout the gelatin structure; a preservative which by a relatively greater affinity for oxygen prevents rapid deterioration of the developer; and a restrainer which is used to cut down the amount of "unexposed" development and thereby prevent fog or "veil." The chemicals ordinarily used are sodium carbonate, sodium sulfite, and potassium bromide, respectively. Although these chemicals perform the functions stated, we should recognize certain facts regarding them, so that in our eagerness to take full advantage of their qualities we do not ruin the developer.

The Preservative.

Although sodium sulfite is added to the developer to prevent too rapid oxidation of the solution from contact with the air, it is not added in any haphazard manner. The factors which affect the amount of sulfite to be used include:

Nature of the developing agent.

Nature of the alkali used.

Degree of concentration of the solution.

Degree of keeping quality desired.

Temperature of the developing bath.

For example, very little sulfite is necessary with glycin, which does not oxidize readily, nor is much needed with a developer like paraphenylenediamine whose oxidation products are colorless. When a heavily oxidizing developer such as pyro is used, a relatively large amount of sulfite is necessary to hold the staining power to a minimum.

Likewise, developers which contain strong caustic alkalis such as sodium hydroxide oxidize more readily than those made with the carbonates, and so require the use of a greater amount of sulfite. In the matter of dilution, the proportionate amount of sulfite used in a dilute developer is greater than in a concentrated one.

These conditions, however, are subject to other factors. Although not common practice, it is advisable to make all developing solutions fresh, **except** in the case of those which have special properties which are gained only with aging or ripening. For a freshly made developer which is to be used and discarded, the sulfite concentration need not exceed one per cent, or about four and a half grains to the ounce. According to Mees,⁴ the solubility of silver bromide is least at this concentration, and the chances of chemical fog are lowest. For developers which are to be kept for

⁴ Mees and Piper, *Phot. Jt.*, 51, 1911.

a time, particularly in partially-filled bottles or open tanks, the sulfite content must naturally be increased. Another factor which calls for added sulfite is high temperature. This is because a warm solution tends to oxidize more rapidly than a cool one.

Silver bromide is soluble in sulfite, and so the sulfite content of a developer produces an action similar to that encountered in physical development. The silver is redeposited upon the tank or film racks and also upon the image which is developing. This deposit strengthens the image; but when there is no image in the immediate vicinity, such as in deep shadows, the free silver is deposited upon the face of the film producing a **chemical fog**, and its formation is hastened by old or warm solutions. This property of sulfite, by virtue of which it attacks the silver bromide grain, is used in some developers, such as the borax type, to prevent grain clustering of the type which is responsible for graininess. In addition to preserving the activity of the developing agent itself, the sulfite usually prevents any deep discoloration which might stain the gelatin during the process of development.

The Accelerator.

Because the role of the alkali is so complex, it is usually stated that the alkali brings about an incipient destruction of the gelatin structure to permit a ready penetration of the developing solution. While this may be figuratively true, to a degree, it is actually a misrepresentation of fact. A pure solution of hydroquinone in water will not produce development, but the addition of as little as five per cent of sodium hydroxide will produce an acceptable image in two and a half or three minutes. Some of the developers will, after long immersion, produce an image if sulfite is added to the solution, but development as we understand it is usu-

ally dependent upon the use of an alkali. This may be the hydroxide, the carbonate, or a less destructive agent such as tribasic phosphate.

We have already discussed the probability of the electrolytic theory of development. If that is accepted, we have in the alkali the necessary electrolyte. This is one role which may well account for the tremendously increased rate of development in the presence of the alkali. This gives us a different picture of the "destructive" action of the alkali. It is true that the hydroxides will actually produce some disintegration of the gelatin if their action is prolonged, but a five per cent solution of carbonate will not cause gelatin to swell as much as will pure water, while a fifteen per cent solution of carbonate causes only about one-fifteenth of the swelling produced by the five per cent solution. As a note of interest, it may be added that saturated solutions of alkaline carbonates have been used to produce an extremely rapid drying of gelatin films saturated with water. At the same time it must be remembered that the carbonate does greatly accelerate the penetration of the developing solution into the gelatin of the emulsion.

The alkali serves another purpose in the developer. When the silver bromide grain is reduced to metallic silver, bromine is freed. This takes up hydrogen to form hydrobromic acid, and if the alkali were not there to neutralize the acid, development would shortly stop. Even this does not terminate the role of the alkali. When the developer is in the form of a salt, the alkali acts to release the active base, and when the developer is one of the phenols it reacts with the phenol or some part of it to form a salt. Thus we do not necessarily make use of the developing agent which is added to the solution, but some other form of it which in many cases is not directly available as a separate chemical.

It would seem logical to make use of the strong

alkali, such as the hydroxide, and dilute it to the strength necessary to procure the necessarily weak action. Such reasoning is logical, but it ignores the reservoir action of the carbonate. The carbonate in solution dissociates into the bicarbonate and the caustic form, so that while the weak caustic would soon be used up, the carbonate provides a constant source of supply for a small amount of the caustic.

The Restrainer.

We have already seen that there are factors which tend to produce developed grains of silver where there was no exposure to light. This tendency may be controlled largely by the use of correct amounts of preservative and accelerator, by using an alkali which is not too energetic, and also by the use of some reducer which has a slight fogging tendency.

In addition, most developer formulas call for the use of a chemical restrainer, usually potassium bromide. The value of bromide in a developer is sadly overrated and widely misunderstood. The first fact to remember is that the absolute minimum amount of bromide which will serve the purpose is the best quantity to use.

There is a popular concept that certain developers will increase or decrease the speed factor of an emulsion. As this factor is an inherent quality of the emulsion, such a concept is the height of absurdity. The truth is that some developers are more efficient than others, and therefore less exposure is required when they are to be used. However, as long as the real meaning of the term is understood, we may say that the use of bromide in a developer is deliberately inviting a loss of emulsion speed. In other words, if three negatives are exposed and each one given half the exposure of the preceding, it would be possible, by

adding enough bromide, to obtain three practically identical negatives from the three exposures.

If the bromide caused a proportional loss of tone value it would not be so bad, but it acts just like underexposure, that is, the shadow detail suffers while highlights are hardly affected at all. So marked is this effect that many old-time photographers would load

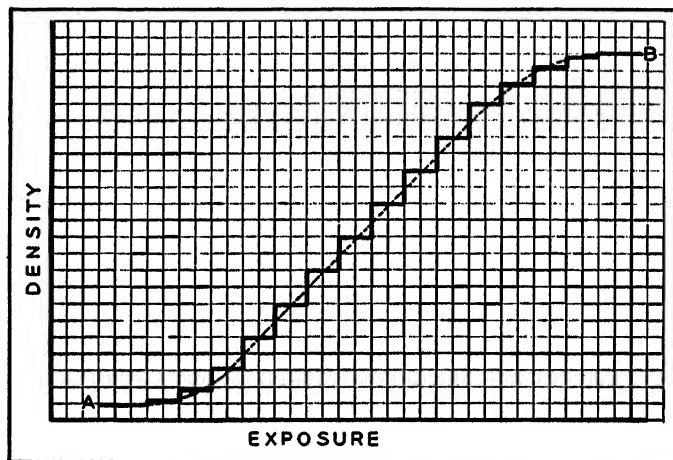


Fig. 10. Curve AB, based on set of steps, represents negative density produced from series of equally increasing exposures.

up the developer with bromide after making an overexposure and thus obtain a passable negative.

The Characteristic Curve.

In Fig. 10 is shown a curve, AB, which represents negative density produced under certain conditions from a series of exposures. This curve has drawn across it a set of steps, each showing the relative density for an equally increasing series of exposures. It

will be seen that at the beginning and end of the curve the steps have little height. That is, there is only a slight increase in density every time the exposure is increased by a definite amount. In the central or straight portion of the curve the steps are about as high as they are wide, showing that there is an in-

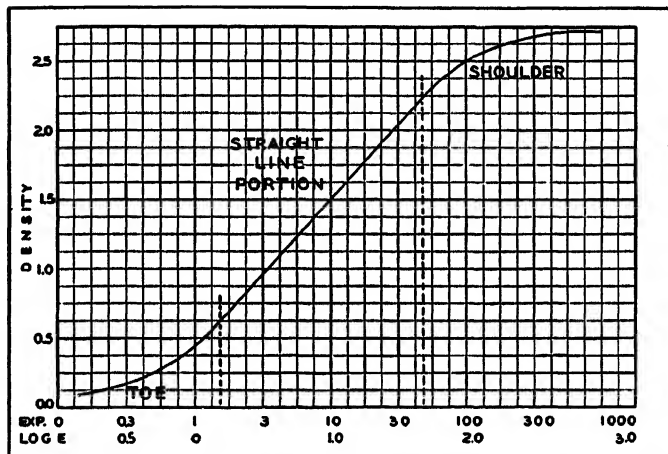


Fig. 11. The characteristic curve, showing toe, straight line portion, and shoulder. It is indicative of a series of steps.

crease in density corresponding exactly to the increase in exposure. The portion of the "curve" drawn through these steps is a straight line, known as the **straight line portion of the characteristic curve**.

Interpreted in terms of a picture, the straight line portion of any exposure is that range of tones which are proportional to the intensities of the light in the original subject. Ordinarily the actual steps are not shown in drawings of characteristic curves (Fig. 11), but the straight line portion is recognized as indicative of the series of steps.

When the characteristics of an emulsion or of a developer are to be investigated, a film is given a series of known exposures. As a rule the exposures advance in geometrical progression, that is, 1, 2, 4, 8, 16, etc. After the exposure has been made, the negative is developed and the densities are read. As density is a logarithmic factor, the logs of the exposures are used as a basis for the graph.

In the underexposed part of the film—that is, the shadow tones—the increase in density is comparatively slight for equal increases in exposure. This forms a curve known as the “toe” at the bottom of the graph. Farther along, each increase in log exposure produces the same degree of increase in density. It must be noted that the increase in density need not be equal to the increase in exposure, although it may be so. When this happens, the straight line rises at a 45-degree angle, and exposure and density are exactly proportional. However, the straight line may lie at any angle to the base, and the steeper this angle the greater will be the **contrast ratio** or **gamma** of the negative. At the top of the graph the line breaks to make a curve opposite to the toe, because the highlight tones are similar to the shadow tones in being only slightly separated. This portion of the curve is known as the “shoulder.” In Fig. 11 the region between the dotted lines is the straight line portion of the curve. Later we shall see how gamma is derived from this characteristic curve.

If characteristic curves are made of negatives developed in solutions carrying different amounts of bromide, the gamma will not be materially affected, but there will be a constant regression of inertia * just as you would find if you used emulsions of constantly decreasing sensitivity. At the same time the changing shape of the toe of the curve will tell the story of lost shadow detail (Fig. 12).

* See Chapter IX.

Most modern emulsions contain a minute quantity of soluble bromide and are best developed in solutions which have no added bromide. The best guide to follow in this respect is the formula provided by the manufacturer of the film. He knows what his emulsion contains, and his recommended developer is balanced to his own emulsion. So, if you find that the ABC

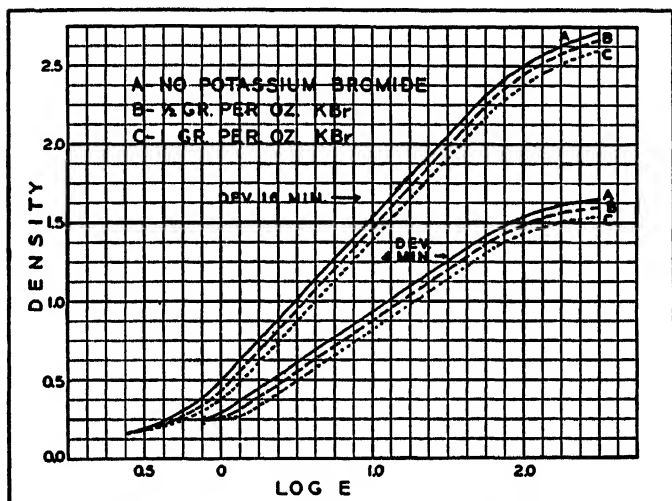


Fig. 12. When bromide is added to a developer, relative changes are unaffected, but it acts like a corresponding underexposure.

developer works excellently with the ABC films, do not assume that therefore the ABC developer is best for XYZ films also.

Many amateurs lose sight of the fact that during development the solution takes up some additional bromide, the quantity increasing with the emulsion area which has been developed. Not only this, but oxidation products of the developer also accumulate,

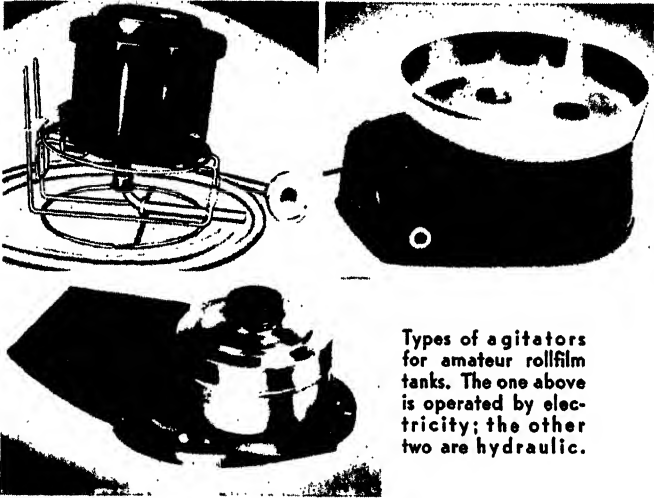
so that we have a definite limit to the developer life. It must be remembered that there are some developers, such as borax, which are kept for long periods of time through the addition of fresh solution. The fresh solution prevents a too great accumulation of unwanted products, so that no effort should be made to conserve the total original solution for too long a period.

Waste Products.

When a portion of the image is developed, the solution which has done the work has taken up additional bromide and oxidation products which make the solution heavier than the original and also give it a retarding action as regards subsequent development. If the negative is being developed in a vertical position in a motionless tank, the solution which has developed the image at the upper part of the negative sinks downward because of its increased density. This carries it over the lower part of the negative where it retards development. However, as it sinks, the lighter fresh developer flows in at the top and there development proceeds normally. As a result the negative presents a constantly decreasing density from top to bottom. If there are obstacles to free circulation, such as perforated metal racks or even perforations in the film, the variable action of the charged developer will be seen as streaks across the negative.

If the negative is developed in a horizontal position, the diffusion of the waste products away from light colored objects (dense negative areas) will inhibit development at the border of the area and surround the light object with a black line. If the original subject was made up of patches of various sizes but all of intermediate tone value, the smaller patches will develop to the greatest density, and in all patches the edges will have greater density than the center.

When some means is used to keep the developer agitated during the process of development, these faults are reduced to a degree where they are of no



Types of agitators for amateur rollfilm tanks. The one above is operated by electricity; the other two are hydraulic.

moment. The agitation accelerates development by providing fresh developer to the negative all the time, and it also prevents loss of contrast and dropping developer potential, both of which would be serious in a stagnant developer.

Chemical Fog.

We have mentioned, from time to time, the development of unexposed grains of silver bromide. The cause seems to lie in the fact that in the manufacture of the emulsion there are some grains which are far more sensitive than others, and these will develop whether they have been exposed or not. The number of these grains will vary in different types of emulsion,

and usually, although by no means always, the faster emulsions have a greater number of such supersensitive grains. There also seems to be a progressive deterioration within the emulsion, so that an old emulsion is far more likely to fog than a fresh one. Developers which contain an excess of alkali or sulfite tend to produce excessive fog, and warm developers are worse in this respect than cool ones.

One might assume that low-potential developers would give less fog than the more active high-potential ones, but this is not the fact. Amidol and metol, with potentials of 30 to 40, and 20, respectively, tend to give less chemical fog than do pyro and hydroquinone with potentials of 16 and 1 respectively. It is interesting to note that with high-potential developers, the addition of bromide restrains fog to a greater degree than it does the image, so that bromide may be used advantageously, whereas with low-potential developers it tends to do more harm than good.

Strangely enough, fog is encountered more often in weak than in concentrated developers, while the removal of a negative from the developer before development is completed (as in developing negatives by inspection) almost invariably leads to fog. An unexposed emulsion when developed exhibits more fog than does an exposed one, but even in the exposed film there is often sufficient fog to decrease the contrast and in some cases even to mask the more delicate detail in the image. Because there is a great amount of bromide released in the highlights, there is very little fog here, but in the weaker shadows the fog piles up, and this uneven accumulation of bromide tends to flatten the contrast which otherwise would be obtained.

There are some desensitizers which apparently have the power to eliminate chemical fog and to do this without any marked loss of speed or change in contrast. Many amateurs make a practice of using de-



Degraded print made from a negative marred by chemical fog.

sensitizers for all-dark development simply because of the clean, fog-free negatives which are obtained.

Desensitizers.

This class of chemicals acts as narcotics upon the emulsion. According to Dr. Lüppo-Cramer, the desensitizer has weak oxidizing power which enables it to prevent the formation of free silver by exposure, although it is not strong enough to act upon the silver already deposited by the original exposure. While the desensitizers are largely dyes, their coloring has no effect upon their specific desensitizing action. A desensitizer may be made up as a single solution in which the film is bathed before development, or combined with the developer. After desensitization it may be developed in a moderately bright darkroom light provided



After desensitization, film can be examined in orange safelight.

the safelight is of such a shade of yellow or orange that the blue and violet components are entirely removed. The green and yellow-green safelights are not satisfactory for use with desensitized emulsions.

The desensitizer would be of little utility if its action were limited to actual desensitization, because there is seldom any reason for visual development. However, there are other reactions of interest which make the desensitizers of great value. First of all there is the tendency to inhibit fog, which is usually so great that the negatives appear to be totally free from fog. Then there is the effect upon the developing agent. With a desensitizer it is possible to push development far beyond the usual limit, and it is possible to use a higher alkaline concentration. Finally, the

typical reaction of the reducer itself is often altered; hydroquinone, for example, acquires properties which make it strongly resemble metol.

There is no freedom of choice as to the method of using the desensitizer **safranine**. One of the most popular desensitizers, it is precipitated by developers of the polyphenol group (pyro, hydroquinone), and even with other developers it cannot be added to the stock solution, but only to the working bath in proportion of about one part safranine to two thousand parts of developer. This indicates that the safranine group of desensitizers should be used as a preliminary bath and not in the developer itself. Among the desensitizers used, safranine probably leads the field. Others include **auramine**, **chrysoidine**, **fuchsine**, **aurantia**, **pinacryptol green**, and **basic scarlet N**. Aurantia is poisonous to some people if allowed to come into contact with bare skin. If it is used, rubber gloves or developing racks or tongs should be used. Pinacryptol green is of secret composition. It acts somewhat like methylene blue mixed with acridine yellow and tends to increase fog with certain emulsions instead of reducing it. Basic scarlet N is a mixture of approximately equal parts of safranine and chrysoidine. It has the desensitizing power of safranine, but does not stain the fingers and emulsion to any degree.

These desensitizers are used in dilutions of 1:1000 to 1:5000. Weaker solutions lose their desensitizing power rapidly. At 1:5000 safranine, pinacryptol green, and basic scarlet N remove about ninety-nine per cent of the original sensitivity of the emulsion, while in dilutions of 1:1,000,000 the reduction in sensitivity is only about ten per cent, which is a reduction of no practical value.

It is important to observe that desensitizers do not actually remove all response to light, but only reduce it to a practical degree. For example, if 1/100 second

exposure to a given light is sufficient to fog a film completely, one second will produce the same result after the film has been "desensitized" in a 1:5000 solution. Even after desensitizing, films must be handled with care, because they can be fogged. Basic scarlet N is one of the most advantageous desensitizers for the experimental amateur. It is made up in a 1:500 stock solution and diluted 1:10 for use (1:5000 working strength). Formalin added to the stock solution in a strength of two-tenths per cent will give the stock solution excellent keeping qualities.

Non-Chemical Factors.

There are other factors affecting the development which are not, strictly speaking, chemical. These factors include the important ones of **dilution** and **temperature**. The effect of dilution depends upon the developer itself. A slight dilution in any case affects the speed of development and the formation of fog, while considerable dilution may affect the character of the image. This is apparently a compound factor of the concentration of the bath itself and of the rate of oxidation encountered. For example, when a non-oxidizing developer such as glycin is used, a half-strength developer used twice as long will give a result which is almost identical with the normal. Here the effect of dilution is least, its only important complement being the increased time of development. In other developers which oxidize in air readily, this oxidation causes a loss of strength, and the time complement must be made disproportionately large. Dr. B. T. J. Glover, in 1923, reported that if Rodinal were used at 1:100 instead of the normal 1:20 dilution (that is, a further dilution of 1:5), the time, instead of being increased five times, would really demand an increase of from six to nine times.

As the dilution is increased, there is a further change which is not based in any way upon the concentration-time complement. Development progresses because the water of the solution carries the developing ingredients into the gelatin. As the developer is diluted, each unit volume of water carries less and less developer. It is obvious that the developer starts to act and is neutralized as soon as it strikes the surface of the emulsion, and that penetration is only possible by the action of water carrying reserve developer into the depths of the emulsion.

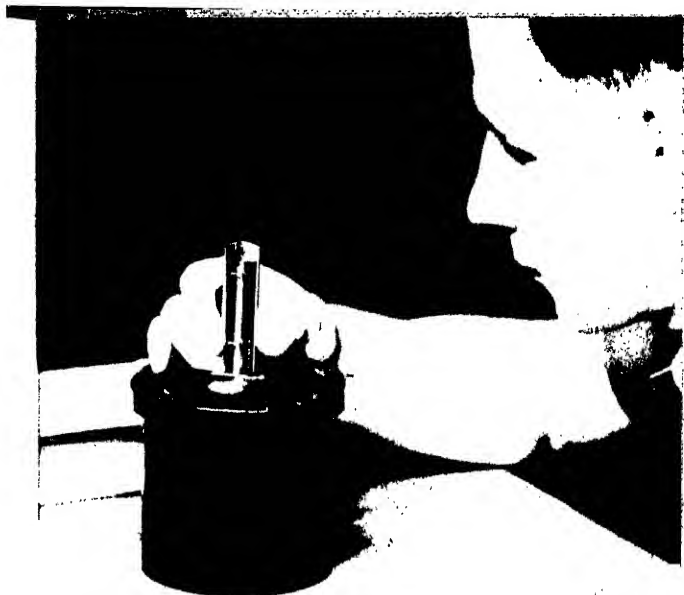
So, because shadow detail is superficial and highlights extend into the depths of the emulsion, a very weak developer will be expended at the surface and all shadow detail will be brought up before the highlights are more than partially developed. This method may be used to reduce the contrast of underexposure without sacrificing any shadow detail which may be there. This is one of the secrets of "developer magic" which isn't nearly as mysterious or valuable as it first appears. In the first place, to get the fullest effect all bromide must be omitted from the developer. Development should be stopped when the shadows have reached their fullest intensity. This means that the highlights are still too thin and the whole negative must then be intensified to bring it up to normal density. The method is of value in reducing contrast, because when development is stopped short of the full time, certain developers will produce a negative which is not equally developed. For this reason, low gamma or compression development is far more satisfactory when done with a very dilute developer than when the normal developer is used for a shorter than normal time.

The dilute developer is so effective at times that it has gained a reputation for being a wonder developer. More detail, increased quality, more faithful propor-

tion of tone, and many other wonderful claims have been made for it. If the film is left in the dilute developer for a sufficient time, the highlights would reach the same density as in a normal bath, and the chances for chemical fog in a dilute developer are far greater than in one of normal concentration. The dilute developer does not produce greater detail nor any better quality, except that the patience of the photographer is exhausted before the highlights become clogged, and he is fooled into thinking that he has a non-clogging developer.

Temperature, too, plays an important role in photography. Almost all chemical reactions progress more rapidly as the temperature is raised, but in development we find again the dissimilarity of reaction between the exposed and unexposed grains. As the temperature rises there is an increasing tendency for the unexposed grains to react; that is, the chemical fog increases with greater proportional rapidity than does the image. This establishes a temperature limit which can be raised by the use of additional bromide in the developer.

Developers have a more or less constant factor which indicates the ratio between the time periods which will give identical results when the temperature differs by eighteen degrees F. (10° C.). However, these factors or **temperature coefficients** are of little practical value, because in a mixture of two or more different developers, each one retains its own individual coefficient. Thus in the usual mixture of metol and hydroquinone, a very low temperature stops the action of hydroquinone, and the negative has the appearance of a negative developed in metol. At very low temperatures the inhibiting effect resembles the effect of underexposure (and is therefore sometimes used for the development of overexposed films). On the contrary,



Temperature is an important factor in negative development.

a warm developer favors the development of underexposed negatives because the temperature rise not only raises the equivalent potential of the developer but at the same time produces a greater degree of chemical fog, and this in turn adds density to the shadows, masking the underexposure effect to some degree.

There is a great deal to be said in favor of the experimenter working with temperature changes, but until considerable experience is acquired it is advisable for the photographer to keep his processing solutions between 65 and 70 degrees F. whenever possible, as this temperature range has been established as the best for general processing.

Minor Factors.

There are still other modifications of the process of development which are used at times, but which lie more or less in the realm of the experimenter. Despite this fact, it must be recognized that many "trick" developers of our day are simply adaptations of these modifications which, although never widely known, have been known to photographic technicians for years. Too often some enterprising individual takes one of these old stunts, incorporates it in a brand new "magic" developer, and promptly makes a fortune. The catch is that every such stunt which is used is available only at the cost of some more valuable advantage.

It cannot be emphasized too strongly that the best developer for any film or plate is the developer which the manufacturer recommends. He is thoroughly familiar with all the "wonder" developers, and has been for years; but he knows that while they may possess some single advantage, they will never give the all-around, universal satisfaction that his carefully balanced developer will give. To be fair, this has no bearing upon the makers of developing solutions for which only normal results are claimed, and which solutions are carefully compounded of pure ingredients to save the amateur the trouble of keeping a stock of chemicals on hand and compounding his own. Nor is it impossible that something new may be discovered by some serious worker.

Our age is an age of discovery, but the chances are that the many skilled researchers in the big laboratories will make the discoveries. On the whole, the secret developer should not be accepted until it has proven itself superior in a series of carefully checked, impartial tests. I have yet to find one which will pass such a test without showing signs of being the same old familiar stuff!

Iodides.

There is usually a minute quantity of iodide present in the emulsion. If it is added to a developer to the extent of about one part in a thousand (1:5000 to 1:500) it will cause low-potential developers to accelerate considerably, particularly as regards the time of image appearance. Developers of higher potential, such as metol, show very little response. The action is the same if the iodide is applied as a preliminary bath or mixed with the developer. Details of the action are not known, but Lüppo-Cramer has advanced the theory that the sensitive nucleus has some protective shield removed by the iodide.

Of more practical importance is the fact that iodide will more or less effectually prevent the appearance of black abrasion marks, and to some extent it acts as a preventive against dichroic fog. Among its disadvantages are the lengthening of fixing time, the reduction in sensitivity, and increase of fog when the concentration advances, particularly in developers of high sulfite concentration. This paradoxical property of preventing and promoting dichroic fog are merely two effects depending upon concentration.

Neutral Salts.

We have already noted that gelatin will swell much less in a solution of sodium carbonate than in pure water, but this fact cannot be used to great advantage because the carbonate is an active part of the developer. However, there are other salts which exert a similar inhibition upon the swelling of the gelatin, yet which do not take any particularly active part in the development reactions. These salts include **nitrates, phosphates, oxalates, sulfates**, and so forth. Because of its cheapness and availability, sodium sulfate is usually chosen. It is not truly neutral because when it is

added in sufficient quantity to prevent dangerous swelling at high temperatures, it also retards development. But, as development would proceed much too rapidly at the high temperature, the combined action of retardation and non-swelling has made this the favored ingredient of "all-temperature" developers.

Hypo.

Hypo is sometimes added to developers with the idea that it gives more brilliance to the negative. Actually it retards development, decreases density, and increases the tendency to fog. Under some conditions it is possible to add sufficient hypo to the developer so that development and fixing will take place together, but this is a process not widely used.

Viscous Solutions.

Many advocates of the use of syrups have from time to time told of the wonders achieved by their own particular syrup. Glycerin, glucose, ordinary sugar, and similar heavy liquids have been added to developers. The idea is to retard the rate of diffusion of solution into the emulsion. The theory is that development will thus be limited to the surface of the emulsion, and that contrast and grain thereby will be lessened. Actual experiment, however, has shown that beyond increasing the time of development somewhat the action is largely negligible.

Summary.

The photographic developer is a complex solution whose function it is to reduce to metallic silver those grains of silver bromide which have been exposed to light, and to leave unexposed grains unaltered.

This ideal is not fully realized, but it is approx-

imated through the use of the complex solution containing a chemical reducer which does the actual developing, sometimes called the **developing agent**; a **preservative** to prevent interaction between the reducer and the oxygen of the air; an **accelerator** to facilitate the chemical action between reducer and exposed grains; a **restrainer** to retard development of unexposed grains; and minor additional substances added to the developer for various real or imaginary reasons.

The developer will function in a variety of concentrations and at various temperatures. Solutions made with varying proportions of multiple reducers will function in a way which partakes of the characteristics of both or all reducers.

Time is a function of temperature, and to a lesser degree it may be used as a contrast control, although contrast is more readily controlled through variation of concentration.

The action of the various ingredients is not limited to their basic function. The additional effects may, as in the case of the alkali, be advantageous; or, as in the case of bromide, a handicap. The specific action of some ingredients, such as sulfite, may change considerably with concentration, and, as in the case of iodide, increasing concentration may produce an effect directly opposed to that of the weaker concentration.

The type of developer is chosen to suit the work to be done. It is made up with due attention to the effect of proportions of the various ingredients. Care is taken to insure the freshness and purity of the chemicals used; this care is extended to the water which may have natural alkali or other soluble salts which will exert some effect upon the development. The solution is used in a suitable container or tray. The film is immersed in the solution and care is taken to insure the absence of bubbles or foreign matter. The solution is allowed to act for a definite period of time

at a definite temperature, and agitation either at intervals or throughout development insures uniform developer action.

The fact that the developer is permitted to act for a definite time at a definite temperature does not indicate that these definite units must of necessity be the "standard" units. The specific limitations are those which will give the best results following the exposure which has been given.

Post-Development Treatment.

The developed image is the end for which the photographer works, but his task is not completed when development is finished. Although we have made use

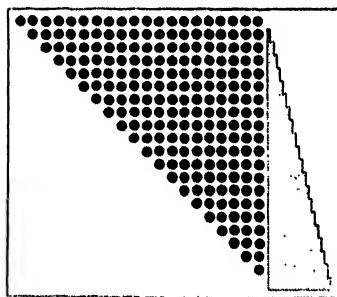


Fig. 13. After development the residual sensitive silver halide must be removed to prevent its blackening. This is done in a fixing bath as described.

only of certain selected sensitive grains, the unused ones are still in the emulsion and **still sensitive**.

There is one point which often confuses the beginner about this stage of the processing. If the film is removed from the developer and rinsed well, it will not be injured by a slight exposure to light. True, the remainder of the sensitive emulsion will be **exposed**, but it will not be **developed**. Therefore, unless the film be returned to the developer, a slight exposure to light

after development and before fixing will not injure the negative.

To make the negative usable it is necessary to remove from the emulsion all this unused (undeveloped) silver bromide (Fig. 13). After that is done, instead of an emulsion there will be a mixture of metallic silver grains supported in a film of gelatin. As neither silver nor gelatin is particularly susceptible to light action, the negative may be handled freely in any light.

Fixing Agents.

The choice of agents which will remove the unexposed bromide without affecting the deposited metallic silver is limited. In fact, the three agents most commonly recommended—potassium cyanide, ammonium thiosulfate, and sodium thiosulfate—all attack the deposited silver as well as the bromide. Potassium cyanide, besides being extremely poisonous, attacks the silver bromide so strongly that it has little fixing value except with iodide suspensions which are now practically never used. Ammonium thiosulfate removes the undeveloped bromide rapidly, but it is unstable, and the ammonia fumes make it unpleasant to use. This leaves the sodium thiosulfate, or *hypo*, universally used as the fixing agent.

Hypo is sometimes called "sodium hyposulfite," which is an unfortunate error inasmuch as sodium hyposulfite is an entirely different substance, having the formula $\text{Na}_2\text{S}_2\text{O}_4 \cdot 2\text{H}_2\text{O}$, whereas sodium thiosulfate, the photographer's "hypo," has the formula $\text{Na}_2\text{S}_2\text{O}_3 \cdot 5\text{H}_2\text{O}$.

The Fixing Bath.

Hypo in alkaline solution has very little effect upon metallic silver, but unfortunately the use of the alkaline

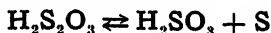
bath is not practical. It will be recalled that one of the most important constituents of the developing bath is the alkali, and obviously the developing bath is alkaline. When the negative is removed from the developer it is filled with the alkaline solution, and even when rinsed there is a considerable alkaline concentration carried over. Not only is there a tendency toward excessive swelling in an alkaline fixing bath, but there is a considerable danger of dichroic fog and other silver stains occurring. Finally, in the alkaline bath the imbedded developer will continue to develop until the bromide is removed, and this almost always results in uneven development.

The obvious remedy is to make the fixing bath neutral or acid. The neutral bath attacks silver very slowly, but in practice the neutral bath would rapidly become alkaline by the introduction of developer. The practical solution is to make the fixing bath definitely acid. It is true that hypo in acid solution attacks silver and other metals rather vigorously. Under some conditions the continued action of an acid hypo bath for as little as forty-eight hours is sufficient to bleach the image completely. This is hardly a serious disadvantage, however, as there is no need to soak a negative or print in hypo for two days.

Of course there is the partial remedy of using an acid stop bath between the developer and the hypo. But as ordinarily made and used, the stop bath is a snare and a delusion. If the bath is renewed often enough to keep it acid, so much the better, but the usual procedure is to take a negative or print from the developer, push it into the stop bath, pick it up, drain a second, and so into the hypo! True, it does remove the surface developer and to that extent prevents many stains which would otherwise occur; but to use the stop correctly the negative should remain in it at the very least a full minute. This means sixty seconds by

the clock, a period of time which is usually estimated mentally as between ten and fifteen seconds. The miniature negative technique of five full minutes in a chrome alum-bisulfite bath is the kind of stop bath which really works.

But that is pure digression. Having determined to make use of the acid hypo bath, the next step is to acidify it. The direct addition of most acids to a solution of hypo results in the precipitation of sulfur. According to Neblette the reaction is a reversible one.



According to the chemical equation the free acid of sodium thiosulfate (thiosulfuric acid) is broken down into sulfurous acid and sulfur, and these in turn recombine to form the thiosulfuric acid. In the bath what we actually have is the decomposition of hypo into **sulfite** and **sulfur**, and back to hypo again. If there is an excess of sulfite added to the solution this reversible reaction is blocked, and the hypo remains stable. Moreover, the sulfite plays the same role it does in the developer, namely, preventing discoloration by oxidation products, and thereby acting as an efficient stain preventive.

Inasmuch as alkaline developer is constantly being carried into the fixing bath, the need for a considerable amount of acid is obvious. On the contrary, too strong an acid will precipitate the sulfur in spite of the sulfite; so it is necessary to resort to acids which are inherently weak yet which have a full neutralizing power. One of the best is **acetic acid**, although E. J. Wall once offered a **citric acid** bath of considerable merit. It is possible to acidify the hypo by the addition of **sodium bisulfite** (NaHSO_3). The addition of this chemical is closely analogous to the addition of sulfite and sulfurous acid; it takes care both of the preservative ac-

tion and the acidification of the solution. While such a bath is widely used, it is not as efficient as that using acetic acid and sulfite.

The use of the terms **strong** and **weak** as applied to acids has nothing to do with their concentration; that is, you cannot make a weak acid of a strong acid by merely diluting it. The terms refer to inherent characteristics of the acid itself, and indicate the proportion of the acid which is ionized in solution. Thus while acetic acid ionizes only to the extent of 1.3 per cent in 0.1 normal solution, sulfuric acid ionizes to 61 per cent and hydrochloric to 92 per cent at the same relative dilution. For further work in this field, John H. Yoe's excellent work, "Chemical Principles," is highly recommended.

The Hardener.

So far we have determined the advantage of a hypo bath which is sufficiently acid to prevent undue swelling of gelatin, which will neutralize the alkalinity of the developer, which will prevent staining, and which will resist decomposition. There is but one other factor to consider, and this is the fragility of the gelatin after passing through the preceding solutions. It is generally recognized that some kind of tanning or hardening is advisable. This may be done in an intermediate bath between developer and fixer, but more commonly the gelatin is hardened while fixing by the addition of **alum** to the hypo solution.

Alum, either the white **potassium alum** (potassium aluminum sulfate), $\text{Al}_2(\text{SO}_4)_3 \cdot \text{K}_2\text{SO}_4 \cdot 24\text{H}_2\text{O}$, or **potassium chrome alum** (potassium chromium sulfate), $\text{Cr}_2(\text{SO}_4)_3 \cdot \text{K}_2\text{SO}_4 \cdot 24\text{H}_2\text{O}$, renders the gelatin tough and leathery, the action proceeding best in alkaline solution. This would work havoc in the developer,

so the alum is added to, and does its work satisfactorily in, the acid fixing bath.

When hypo and ordinary white alum are mixed in solution and boiled, both are completely decomposed. Sulfur and aluminum are precipitated, sulfur dioxide is liberated, and sodium sulfate is formed in solution. When the reaction takes place at ordinary temperature, aluminum thiosulfate is formed, and breaks down into aluminum sulfate and hydrogen sulfide. This reacts with the excess of hypo to form sodium bisulfite and sodium hydrosulfide, with the precipitation of free sulfur. Aluminum sulfate is regenerated, and the reactions continue. This complex cycle is inhibited or entirely prevented by the addition to the hypo of sodium sulfite or bisulfite, or the acetate or citrate of sodium. If the alum-hypo solution becomes alkaline, as it may if too much developer is carried over into it, aluminum sulfite will be deposited **within** the gelatin, and this is almost impossible to remove. This precipitate is white, and in the minute amounts deposited would form a grayish veil over the image, and a particularly objectionable effect in a print. For these reasons the hypo solution is kept acid.

There is some question as to the advisability of using a combined hardening-fixing bath. Many skilled workers claim that there is a loss of quality when such a fixing bath is used. It is beyond question that if negatives are left to soak in the hypo for an hour or so there will be a loss of delicate tones. On the contrary, if the fixing bath is used correctly, there is no reason why the alum bath should injure the negative. It is true, of course, that when the chrome alum-bisulfite bath is used between the developer and fixer, there is no reason for using the alum-fixer. But even in that case the use of the acid fixing bath is advisable. As we are not concerned here with the problems of printing, we shall not go into the subject of fixing prints.

Fixing the Negative.

Having determined that the acid fixing bath (with or without alum) is preferable, what can we expect this bath to do? One thing of importance is to know the conditions under which the bath will work best. We will ignore the cyanide and ammonium salt, limiting ourselves to the use of hypo. One would think that the more concentrated and the warmer the solution the more rapid would be the fixing effect, but this is not true (Fig. 14). A forty per cent solution of hypo is the most efficient strength for silver bromide removal. As the developer is alkaline and the hypo is acid, too strong a solution of hypo sets up a reaction which forms gas and produces blisters beneath the emulsion. Moreover, there is a penetration differential which upon washing causes the hypo to leave the gelatin more rapidly than the water can enter it, and this, too, promotes blisters and frilling. For these reasons it has been found advisable to use the hypo in a strength of twenty-five per cent and less (Fig. 15.)

Ordinarily the working solution is made by dissolving four ounces of the hypo in sixteen ounces of water. This solution acts readily, but if the hypo is reduced to fifteen per cent and ammonium chloride equal to one quarter the weight of the hypo is added, the action is speeded up considerably. However, this is of little real value. What is of more value is the way in which hypo is used and the way in which it should not be used. The usual method of fixing is to continue to use hypo until it is exhausted and fails to clear the film. As hypo is extremely cheap, this is a grave mistake which many amateurs make.

Hypo removes undeveloped silver bromide in an inverse geometrical ratio. If half of the free bromide is removed in the first minute, half of the remainder will be removed the second minute, and so on.

According to Clerc, the disappearance of the milky deposit of bromide indicates that 95 per cent of the silver bromide has been removed. Assuming that this takes five minutes, the end of another five minutes would remove 95 per cent of the remaining 5 per cent, or would leave a residue amounting to one-quarter per cent which is negligible. This is the support for the conventional advice to leave the negative in the hypo just twice as long as is required for complete clearing of the milky deposit.

On the contrary, Neblette tells us (and I hold to his thought rather than to Clerc's argument) that when a

fresh hypo bath is used, the silver salts have, to all practical intent, been removed when the milky appearance disappears completely. However, when the hypo has been used and contains more than two per cent of silver salts, the residual salts are not removed when the film is cleared, nor will they be removed by prolonged soaking in the hypo. The only way to remove them is to put the films in a fresh hypo bath.

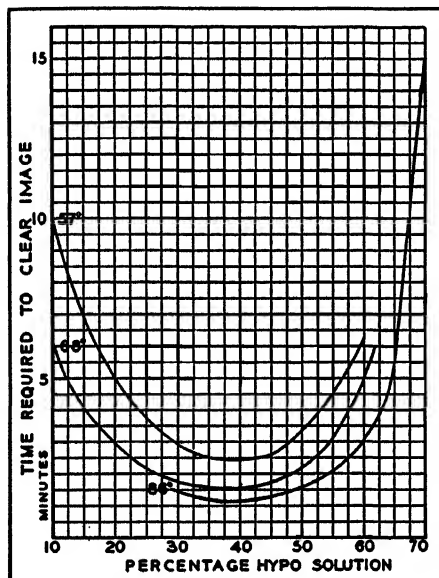


Fig. 14. Showing effect of temperature in fixing with hypo of various strengths, based on time of clearing (after Piper).

For the best fixing, therefore, it is advisable (a) to use a freshly mixed fixing bath and discard it when it has been used, or (b) use a fixing bath which has been used before and fix in this, following it by final fixing in a fresh bath which becomes the used bath for the next fixing. This may appear troublesome and extrav-

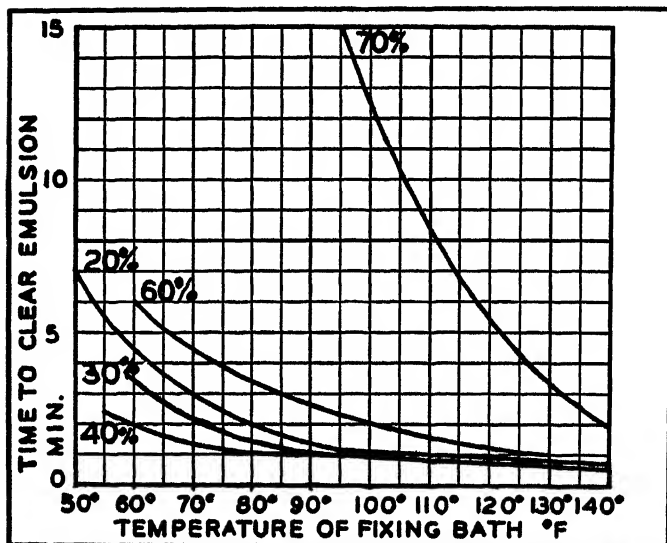


Fig. 15. Fixing action of hypo based on percentage in solution.

After Piper

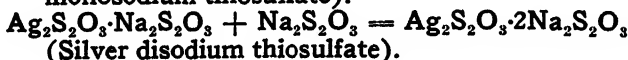
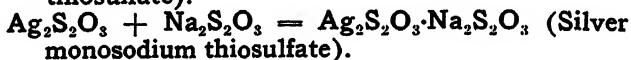
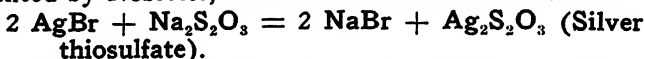
agent, but compare the cost of hypo with the cost of films and you will see that fresh hypo is the best insurance of permanence you can get. Fresh hypo does not necessarily mean freshly mixed, because a large quantity of strong stock can be mixed at one time and portions diluted for use as it is needed; but in that case it is better to have the hardener mixed separately and mix the two when diluting for use.

Life of Fixing Bath.

It is important to know what service we may expect from hypo when it is pushed to its limit. According to the Eastman Research Laboratories, one gallon of the acid-hardening hypo will fix approximately 9000 square inches of film surface. This represents about seventy-five per cent of the maximum fixing power of the same amount of straight hypo solution. As most amateurs use smaller quantities than this, let us break down the quantity. As 9000 is the maximum, we shall assume 7500 square inches as a safe working figure. Dividing this by four we get 1875 square inches of film which can be fixed safely in one quart of hypo. The average 35 mm film contains ninety square inches; this allows 20 films to the quart. The average 120-size roll contains about 72 square inches, so even more could be fixed in the quart of solution. However, these figures are rarely approached in practice, the hypo being exhausted by developer carryover or other decomposition before this optimum quantity is reached. The average $3\frac{1}{4} \times 4\frac{1}{4}$ film has an area of 13.8125 square inches or 165.75 square inches per dozen. This means that a quart of hypo should fix more than ten dozen such films, a feat which few amateurs would have the temerity to attempt. If the average amateur photographer uses his hypo for half the above quantities he will still be getting far more than his money's worth. In fact, I have long contended that any negative that is worth making is worth the quantity of fresh hypo necessary to fix it properly.

But why all the bother about fixing? When the whitish bromide is gone the film is fixed, isn't it? Not at all. When silver bromide is placed in contact with hypo there is an instantaneous formation of silver thio-sulfate which changes at once to complex sodium and

silver thiosulfates. According to Abney⁵ and later presented by Neblette, the reactions involved are:



Silver thiosulfate is insoluble in water, but it is soluble in a solution of sodium thiosulfate. Consequently, it is changed into the second form, the monosodium salt. This, too, is insoluble in water but soluble in hypo, so it is again changed into the third or disodium salt. This salt, being soluble in water, is removed by washing.

It is obvious that the reaction must be complete to the third step before the products can be removed by washing. These salts are formed in microscopic form, and it is easy to understand that they, being in solution, make no visible difference in the appearance of the film. Moreover, the undeveloped silver bromide is also in microscopic crystals, and thus the film will become apparently cleared before the final grains are dissolved. It is estimated that when the film appears clear, about five per cent of the silver halide* is still undissolved, and that there are still certain of the complex salts in the first two forms. To complete the fixing, it is necessary to convert these complex salts and to remove the bulk of the remaining five per cent of silver halide.

Now if the halide conversion does take place in strict geometrical diminution, the theory of Clerc would apparently be upheld, but if there is a progressive increase in the proportionate removal—that is, if the relative rate is increased through the absolute rate of

⁵ "A Treatise on Photography," by Capt W. de Wiveleslie Abney, 8th edition, 1893.

* Silver halide: Term applied to silver bromide, silver chloride, and silver iodide collectively.

removal being more nearly approximated—then the statement of Neblette seems to be logical. In any event, the action of fresh hypo is such that within limits of practical application the Neblette statement can be used as a guide in controlling the fixing step. Therefore, in the general-purpose fixing bath we have:

Sodium thiosulfate. This is the true fixing agent, in this respect being analogous to the reducer in a developer. Its function is to remove the silver halides (bromide, chloride, etc.). It might be added that the removal is not strictly by solution, as a solution of sugar in water, but rather a chemical reaction in which elements recombine to form new products.

Acid, usually acetic. Clearing agent. Increases the penetration of the hypo, and thereby speeds up the process of fixing. It reduces possibility of stain and acts as a regulator for the hardener. Incidentally, it neutralizes any alkaline developer carried over from the first bath.

Sodium sulfite. Acts as a preservative through stopping oxidation. Prevents decomposition of the sodium thiosulfate.

Alum. Hardens the gelatin and tends to prevent frilling, blisters, and reticulation.

Washing.

When the negative is fixed the gelatin, in addition to the metallic silver of the image, is impregnated with the soluble silver disodium thiosulfate. If fixing has not been complete, there will also be present some of the silver thiosulfate and the monosodium thiosulfate, both of which are insoluble in water. If these salts are left in the gelatin they will in time produce silver sulfide, and the image will turn yellowish—in other words, it will “fade.”

Referring to the statement of Neblette, no matter

how prolonged the fixing may be, if the hypo contains in excess of two per cent of silver salts there will not be a complete reaction, and no amount of washing can remove the two insoluble forms. Therefore, it is evident that the most important factor in the removal of the hypo and other salts is not the washing itself, but the matter of thorough fixing.

When the negative has been thoroughly fixed, washing is a comparatively simple matter. Under such conditions the materials to be removed are hypo and the soluble disodium salt. Both are removed easily. As a matter of fact it is an error to speak of "removing" these salts because they literally jump out of the gelatin. Because of osmotic pressure, the salts are actually forced out of the gelatin until the wash water has taken up a sufficient quantity to be of the same salt concentration as the gelatin. When the film is first removed from normal hypo and placed in pure water, this pressure may reach as high as five pounds per square inch. However, when equilibrium has been established, no further removal of hypo is possible until the water is replaced with a fresh supply. Then equilibrium is again established, and so on. It is interesting to note certain facts governing the rate of hypo removal. The same time is required in each case to reach equilibrium, although in each period of time only half the preceding amount of hypo is removed. This is in accord with the rate of fixing, but there are so many factors affecting actual washing that this is of greater theoretical than practical interest.

The equilibrium period is usually stated to be about five minutes, which is about right, but as two minutes are sufficient to reach approximately 99 per cent equilibrium, it is more practical to accept the two-minute base. Assuming that a 5x7 film has been removed from the fixing bath, it will carry with it, in superficial and absorbed hypo, a volume of approximately five

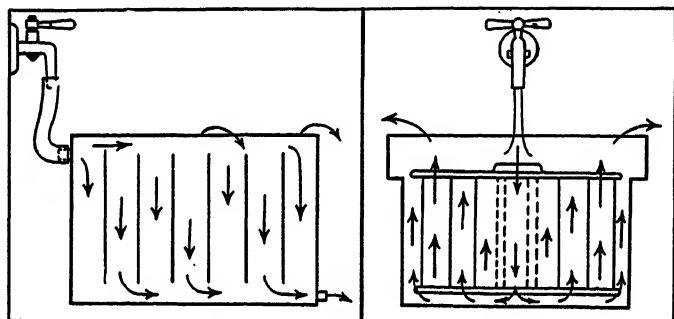
cubic centimeters. Assuming furthermore that the fixing bath was a 20 per cent hypo solution, this means the plate carries with it one gram of hypo. If it is placed in a container with 95 cc of water, the total liquid volume will be 100 cc. Equilibrium will be reached at the concentration of one per cent (1 gram hypo in 100 cc water). This is one-twentieth of the original. Repeating the same washing, the concentrations after each washing will be: 0.05, 0.0025, 0.000125, 0.000006. According to Hickman and Spencer a residual hypo concentration of 0.0036 gram in a 5x7 film will have no bad effects upon the silver image. If we assume that the gelatin of this plate will carry 3 cc of solution, and if we increase the safety margin tenfold, we can assume washing to be complete when the concentration has reached $0.00036 \times 100/3$. This is roughly 0.01 per cent. Referring to the values given above, it will be seen that the third stage of equilibrium will reduce the concentration to one-fourth this required minimum. In other words, after the third equilibrium the concentration will be only 1/40 part of that which has been stated to be safe!

If we are content with the 99 per cent equilibrium of the two-minute base period, the third such equilibrium will still provide a wide margin of safety, thus making it possible, with proper care, to wash negatives thoroughly in six minutes. (The hypo absorption by the paper base introduces an altogether different factor in the case of prints.)

It must be noted that such a period of washing will serve only when every precaution is given to correct conditions. The film must have free access to the water. For example, if the film is laid face up at the bottom of a tray or tank, the water saturated with the dissolved salts will blanket the film while the water at the top of the container remains practically salt-free. A vertical film will have the top edge completely

washed before the bottom. In vertical tanks there should be a considerable free space below the bottom edge of the film, and in all cases there must be sufficient agitation to make sure that complete equilibrium has been established.

It will also be noticed that the above statement refers to the washing of a single plate in the amount of water indicated, and so placed that the salt-charged water may easily be replaced by fresh water. In the



Methods of washing negatives in cut film tank (left) and roll-film tank (right). Note how hypo-laden water is carried away.

practical aspect of washing a number of films, or a long roll, the conditions may be approximated only by insuring a constantly replenished supply of fresh water.

Hypo-charged water is heavier than pure water. If the films are placed in a tank and water run into the top, the fresh water simply skids off the surface and down the drain while the hypo laden water in the bottom of the tank is little affected.

In practical washing of films (and plates), several efficient methods can be used:

1. If the tank has a drain at the bottom, this drain may be partly opened and water run into the top of the

tank faster than it runs out of the bottom. This keeps the tank full, yet it constantly drains off the heavy hypo solution at the bottom.

2. In a tank without bottom drain, a hose with a small nozzle (which may be made by drawing out a piece of glass tubing to small diameter) is inserted in the tank in such a way that the force of the stream carries the fresh water to the bottom of the tank, forcing the hypo solution out at the top.

3. In a period of twenty minutes washing, the tank may be emptied completely every three or four minutes, thus combining the running water and change bath systems.

4. The water may be added and allowed to stand stagnant, the tank being emptied and refilled every three minutes for twelve changes.

5. Using the ordinary rollfilm tank, it is advantageous to combine methods 2 and 3. The tank is emptied three times during washing and so eliminates any small portion of the hypo which might get caught in some eddy current and so escape being flushed out.

Hypo Tests.

The degree of development is apparent to the eye and may further be checked by instruments, but the efficiency of the fixing and washing operations is not so easily checked. There are some rule-of-thumb methods for checking hypo. If the solution gets gray and milky it should be discarded. If it froths badly when beaten by shaking the fingers in it, it is to be discarded. A rough approximation may be arrived at by calculating the area of film surface fixed, but to do this with any accuracy it is necessary to know the bromide concentration in the various films which have been fixed as well as the quantity of solution carried out of the bath by each film. It is said that when the fixing bath

requires double the original time to remove the visible opalescence it is exhausted. This is entirely too true to be of value, because when the bath requires twice its original time to act it is far too weak for any satisfactory use.

A satisfactory test is the drop test. A drop of the hypo solution is placed on filter (blotting) paper and exposed to direct sunlight and kept moist. If it turns brown the bath should be replaced. For a more scientific method, a small measured quantity of hypo is taken as a sample and to this is added one tenth its volume of a five per cent solution of potassium iodide. If a permanent yellow precipitate is thrown down the bath should be discarded.

As far as washing is concerned, there are several reliable tests which will indicate the removal of all dangerous quantities of hypo. A simple test, yet one which is accurate if properly used, is the conductivity test. This consists in measuring the current which will flow across a fixed volume of the solution when placed in an electrical circuit. The simplest outfit consists of a battery, a sensitive meter such as a milliammeter, and two leads which terminate in plates of about one square centimeter area spaced by about one to two millimeters. The addition of a rheostat will permit setting to any desired reference point. The reference point is determined by taking a reading of the water used for washing. This will take care of any slight natural mineral salt content. The meter is calibrated by making meter readings of a series of hypo solutions in concentrations of 1.0, 0.1, 0.01, and 0.001 per cent. The water from the usual source should be used, and when there is an abnormally heavy mineral content, this masks the hypo and renders the method useless except when a test control is run with distilled water. It might be added that the nature of the natural minerals should be determined, as they may have some



Method of testing drippings from washed film to detect remaining traces of hypo, using a permanganate solution.

undesirable effect upon the permanence of the image.

Of the chemical tests, the starch-iodine and potassium permanganate are the most widely known. A starch solution is made and just sufficient iodine added to give it a pale but distinctly blue color. The permanganate solution is made to such a strength that the color is a pale magenta-rose and the solution perfectly transparent. In both cases the more delicate the color the more delicate will be the test. Just sufficient strength is used to impart a distinct color. If water containing even a trace of hypo is added to either of these test solutions the color will be eliminated. The persistence of the color when water is dripped from the washed negative into the test solution is evidence that the film is washed sufficiently.

It is obvious that these tests indicate the absence of hypo, but the presence of the complex silver thiosulfates does not give a positive reaction, so while washing may be complete, there is no indication that fixing has also been completed.

A positive test may be made if a control film (which need be only a portion of a full sheet) is carried through with the films being processed. After washing, this control film is placed in a solution of sodium sulfide. The appearance of any brown coloration indicates the presence of the complex silver salts, and the films should be returned to fresh hypo for further fixing.

In all these tests it is advisable to run control checks, because the water supply often contains materials which will affect the test. For example, instead of the rough-and-ready permanganate test being made with a straight water solution, it may be done with the following stock solution:

Potassium permanganate	5 grains
Sodium carbonate	5 grains
Water	10 ounces

This solution has an intense violet color. To use it, take four ounces of the water which is being used for washing (that is, the normal water supply). In another beaker collect an equal quantity of drippings from the films. Set the two beakers side by side and to each add one drop of the stock solution. If the pale rose color persists as long in the drippings as it does in the plain water, washing is complete. It may be that there are certain organic materials in the original water which will decolorize the permanganate. If this is true, add additional permanganate to the control until the faint rose color persists, then add an equal amount of permanganate to the drippings, and note the duration of the color. The fading of the color in the drippings in an appreciably shorter time than

in the control indicates the presence of a dangerous amount of hypo.

Hypo Eliminators.

The washing process is sometimes hastened by the use of chemicals which react with the hypo. Such methods can do only two things—change the hypo into some other substance whose presence will not be revealed by hypo tests and which is (presumably) less harmful than the hypo, or convert the hypo into something more easily removed from the gelatin. We have already seen that the hypo is forced from the gelatin under considerable pressure, and a more soluble product would simply mean something forced out under still greater pressure, bringing with it still greater danger of blisters. If the change is one which produces an “inert” chemical which remains in the gelatin, the value of the process must always be open to grave question.

In this connection, about the best presentation of the problem is that of Clerc, who has said, “The idea of attempting to destroy hypo instead of eliminating it is almost as old as photography. This idea is unfortunately opposed to common sense and to a sufficiently large number of experimental facts. To begin with, a chemical action never ‘destroys’; it can only transform, and those who have commended such practice have usually not tried to discover whether the products of this transformation are any less liable to damage the image than is the hypo from which they have been obtained. On the other hand, the substance which actively alters images is not so much the hypo as the insoluble complex thiosulfate of sodium and silver. It is therefore necessary to find out the form in which this salt of silver exists after the action of the eliminator.” To this we should add the pointed comment of Neb-

lette, "Plenty of water properly applied is still the secret of thorough hypo elimination."

Regardless of the method used for hypo elimination, the final result is to be regarded with suspicion; the process is more involved and takes almost, if not quite, as much time as washing, and on the whole represents additional effort with no concrete return. One of the great attractions has been the advertised fact that films may be washed in ten or twelve minutes. These claims may or may not be true. In my own collection there are thousands of films, many of which date back to 1919 and today are apparently in the same condition as when they were first dried. My standard method calls for a maximum of fifteen minutes washing with a routine time of ten minutes, but under a forcible stream of water which will effectually prevent the trapping of hypo solution by eddy currents.

Drying.

Many films are coated on both sides with gelatin, the 35 mm miniature film being an exception. Such films have both faces loaded with water when removed from the washing bath. The surface water is removed by wiping with a squeezed out chamois (which is kept under water, in a closed jar when not in use) or with a viscose sponge. Viscose sponges which are squeezed to hasten their wetting or which are folded or twisted in wringing out soon deposit minute particles of viscose upon the film which are almost impossible to remove. One of the best means of removing superficial water from negatives is to blot them between sheets of special lintless, insoluble paper of the type used for making tea balls. This paper is available from photographic supply dealers.

After blotting, the negative contains about one or two grains of water per square inch of surface, both

coatings to be considered, so that a 4x5 negative of twenty square inches has forty square inches of coating containing from forty to eighty grains of water; and considerably more if the temperature of the wash was appreciably above seventy degrees F. This water is removed by evaporation, and the rate of evaporation depends upon the humidity of the air. In very humid air the film dries slowly, while in dry air, it dries more rapidly. The dried film should contain ten per cent or slightly more water, as thoroughly dry gelatin is brittle and curling.

Relatively dry air—that is, of less than sixty per cent humidity—tends to dry the surface gelatin, “sealing over” the lower strata which remain moist. Upon storing the film, the moisture content resumes equilibrium and the surface becomes sufficiently moist in some cases to adhere to any other film with which it is in contact. Drying should proceed at a uniform rate. There has been some discrepancy in reported results of differences in drying rate. Experimental data show that sometimes the slower drying areas are lighter and sometimes darker. The data are insufficient to indicate the exact causative conditions accurately. Drying may be hastened by forced drafts of warm air, but the temperature should not be excessive, and care must be taken that the forced draft does not project dust particles against the emulsion.

Water drops usually cause a secondary swelling at the edge of the drop with a consequent depression in the center of the area which, after drying, leaves a dark ring surrounding a light center. Drops on the back of a film will retain moisture on the face because the evaporation of the drop on the back has cooled the base sufficiently to retard evaporation from the face.

Films which have been hardened in a fresh alum hardening bath may be dried in the sun if there is no shadow which would cause uneven drying. Negatives

in which the slightest deformation must be prevented, such as color separation negatives, spectroscopic and astronomical negatives, should always be dried under controlled, constant conditions.

Films which are to be subjected to a considerable degree of enlargement should be carefully dried in dust-free, warm air. The best means of accomplishing this is to make use of the film driers which are available. One of the most favored forms is a long metal tube of sufficient diameter and length to permit the film to be hung in it. This tube is inserted in the air pump case. This pump takes in air through a dust-proof filter, warms it, and forces it out through the tube. The air draft prevents dust from falling into the tube, while the filters insure uniform results and freedom from dust.

When speed is demanded there are certain methods available which, however, are not to be recommended if you want to produce perfect, permanent negatives.

A rapid drying method is the alcohol wash. The wet films are soaked in alcohol for a minute or two, to permit the alcohol to mix with the water. The negatives are then removed one at a time, drained for a second or two, and waved rapidly in the air. (In some news rooms it is customary to light the alcohol with a match and permit it to burn off, which it will do without damage providing the film is **safety base**. This method is always dangerous, however, and is definitely not advised.) The alcohol evaporates rapidly, thus drying the film in less than usual time. When pure ethyl alcohol can be used in a concentration of at least seventy per cent the method is quite satisfactory, but it must be remembered that this hastens only the drying and is not a substitute for washing. Denatured and rubbing alcohols deposit their added ingredients and streak the negative.

Another rapid drying method is the immersion of



Film dryers. Two above are home-made, one a stovepipe, the other a cabinet, both equipped with fans. Left: drying by infrared with Wabash Birdseye lamps.

the wet negative in a strong solution of sodium carbonate and drying it without further washing. After drying, it is again washed to remove the carbonate. This, too, is a usable emergency method but should not be used on valuable negatives.

Various salts may be used for the preceding method, including aluminum sulfate and sodium sulfate, but the carbonates are the most satisfactory, either the sodium or the potassium salt. This method, which after all is really only a temporary drying, may be tried as follows: The negative is taken from the wash and immersed in a saturated solution of potassium (or sodium) carbonate for about five minutes. It is then removed, wiped quickly with blotting paper, and then immediately wiped dry with a cloth. The surface appears hard and glossy and may be put immediately to use for printing. But in any event the negative must at some later time (and a time not too long deferred) be washed again to remove the carbonate. Ordinarily the negative may be left in the intermediate stage for some weeks, say two or three, but when this method is used, as it often is, to dry partially washed negatives quickly, the thorough washing should not be delayed more than two or three days.

The Finished Negative.

When the negative has been dried it is ready for use or for storage. At this point we must make a distinction between the photographic and pictorial images. Both are the same image, it is true, but in the photographic image we are concerned with the physical characteristics of the silver deposit and in the pictorial image we are concerned with the pleasing effect of the shapes of the image areas. To differentiate fully we shall, unless otherwise stated, assume that we are working with a negative composed of a series of stripes which range from transparent film through various

shades of gray to an opacity too heavy to be used for printing. In short we shall assume the negative to be the twenty-one-step negative which was used to describe the basic nature of the image. Because any photographic negative is nothing more than a series of different depths of gray tone separated by more or less distinct boundaries, such a negative will permit all our attention to be focused upon the factors involved and prevent distraction by purely pictorial elements.

Density Defined.

Light cannot pass through any transparent material, not even thin glass, without some loss. When the material is the combined celluloid and gelatin of the negative, there must be a substantial loss, even when no gray tone intervenes. As we have seen, there is also a certain development of unexposed halide grains; so all in all our clearest stripe still has a definite absorption. In this discussion we shall consider only the light which passes through the film, as this is the condition encountered in printing.

Having means of measurement available, we can learn the intensity of the initial light and that of the transmitted light. The transmitted light can then be named in terms of the percentage of the original which it represents. For example, if half the light passes through the film, then fifty per cent is transmitted, and so on. This information is useful in many ways, but it is not entirely satisfactory for photographic purposes. Instead of speaking of the amount of light which passes through the negative, we refer to the character of the silver deposit in terms of **density**. One of the first things the amateur experimenter should learn is the true meaning of density.

If a 0.001 mm layer of silver will absorb half the light which falls upon it, a second similar layer will absorb half of the remainder, or twenty-five per cent;

a similar layer will then absorb half the remainder or twelve and a half per cent, and so on. It will be seen from this that the successive absorption proceeds with **geometrical progression** and for that reason, if we are to have any standard of silver deposit it must be one which is proportionate to the mass of the silver, within reasonable limits. This is the reason for using the density factor rather than the transmission.

If light of one hundred per cent intensity falls upon a negative and one fourth of it passes through, we have a **transparency** of twenty-five per cent or 0.25. As the



Two types of densitometers for measuring negative density.

reciprocal of 0.25 is 4, this same film has an opacity of 4. Likewise if another part of the film transmits one-eighth we have a transparency of 0.125, and an opacity of 8. In other words, transparency is expressed as the fraction of light which passes through the film, and the opacity is the reciprocal of this fraction. But this does not give us the desired proportional relationship. It is true that opacity means that we are dealing with the silver deposit, while transparency is based upon the absence of silver. Therefore there must be some relation between opacity and density. Such is the case.

The density (or as it is sometimes called, the absorption constant) is the logarithm of the opacity taken to base 10.

Thus any table of logarithms (logs) will show that the densities which correspond to our opacities of 4 and 8 will be 0.602 and 0.903 respectively. This brings to mind one point which it may be important to remember, namely, the unit density relationships. Density 1 transmits ten per cent of the incident light; density 2 transmits one per cent, density 3 transmits one tenth of one per cent, and so on. Thus density 3 transmits only one one-hundredth as much light as density 1.

Another logarithmic relationship which may prove puzzling at first is the fact that while density 2.0 transmits one per cent of the incident light, the density which transmits fifty per cent of the incident light is not density 1.00 at all but density 0.30.

The thickness of the deposit concerns us only in regard to the amount of light which it will intercept. Therefore, regardless of whether the emulsion may be thin or thick, rich in silver or poor, for our purposes we are concerned only with its density. It may be added, however, that in some special cases such as the pyro negative, where the presence of stain of a nonactinic color alters the basic transmission of chemical light, the measured density is not a true reflection of printing value. However, such exceptions have no direct bearing upon our measurements and comparatively little in practical application to printing control.

Contrast and Scale.

When the negative is examined, the stripes across it will be seen to have a gradually deepening tone of gray until the last stripe is practically opaque. To understand the three representative conditions which char-

acterize negatives we shall have to imagine three separate negatives:

First Negative. This negative is placed in an instrument which measures the transmitted light directly in terms of density. Such an instrument is known as a densitometer. (This and other factors now under discussion will be treated in more detail in Chapter IX). We will assume that the darkest stripe of the negative has a density of 0.30, which means that it stops only about half the light which strikes it. In short, the deepest gray is definitely weak. The other stripes grow even weaker until the opposite extreme is represented by the clear gelatin and base.

In this case the greatest amount of light is one hundred per cent minus the loss in clear base, the least amount of light is fifty per cent, or a transmission ratio of less than one to two. Thus we see that the difference between the extremes is not great, and we learn that a density difference of somewhat less than 0.30 indicates a very slight difference.

In photography we rarely speak of the difference between two tones, but we commonly speak of the contrast between them. So familiar has the word become that we now use it even when the difference is slight. Hence we have such qualifications as high contrast, low contrast, normal contrast, medium contrast, and so forth. In these terms, therefore, our first negative has a low contrast.

Second Negative. In this negative we will assume that the darkest stripe transmits 0.8 of one per cent of the original light, and we will furthermore disregard the slight absorption of the clear base and assume that the transmission ratio is 125:1. In this case the opacity is the reciprocal of 0.08, or 125, and the density is approximately 2.10 (2.09691). This is about the greatest usable range of tone we can get in a negative, so we say that the contrast is "medium" or "normal," re-

ardless of the fact that numerically the difference is 62.5 times as great as in the first negative.

Third Negative. In this negative we shall assume that the darkest stripe will pass only one one-thousandth part of the incident light while the opposite stripe is still clear. This means that the density range is from 0 to 3, while the opacity range is 1000:1, or eight times as great as the difference in the second negative. However, it is impossible to retain such a range of tone in printing, therefore the print will lose several tones by merging them into their neighboring ones, so we say that the negative has high contrast or excessive contrast.

It might be noted here that the term *soft* unless modified in some way refers to an image of low contrast. Softness of focus or definition is usually so designated. On the contrary, a negative of high contrast is usually called *hard*.

There is another designation which we should bear in mind. This is the reference to *scale*. If the contrast transparency ratio is low, such as 1:2, 1:5, or even 1:10, the negative is called a *short-scale* negative while a great difference such as 1:1000 is designated by the term *long scale*. Because hard negatives are printed on soft papers and vice versa, there is some confusion regarding scale because a short-scale negative is printed on a short-scale paper, but a short scale paper is a hard paper, requiring only a few times its minimum exposure to produce the fullest black.

These terms refer to the actual silver deposit in the negative and have no imaginable relationship to the specific contrast, or *gamma*, although the word "*gamma*" is often used to denote the degree of contrast in any negative.

When an emulsion is given a series of known exposures and the negative is developed, the densities of the various deposits are measured. These densities are

plotted against the base ten logs of the exposures. This graph results in an S-shaped curve known as the characteristic curve of the emulsion (see Fig. 11, page 69). It is valuable in determining the characteristics of some particular film, or the properties of some developing procedure. But too often you will hear a photographer speak of the various exposures on a single roll of film, all developed at one time, as having a "high gamma" or a "low gamma." Such a thing is an absurdity, as the gamma would necessarily be constant for the entire roll.

We will discuss this at greater length in Chapter IX but for the present be warned not to confuse the contrast scale of a negative with gamma. The original contrast of the subject, the lighting used, and the colors of the subject may well affect the contrast scale, but such things will not affect the gamma. Having accepted the fundamental importance of the density of the silver deposit, there are other factors which must receive some attention.

Graininess.

Close examination of an enlargement from a negative will show that large areas of monotone have a finely granular appearance. This is the graininess of the negative. It has been so often repeated that graininess is the projected image of the silver grains in the emulsion that the explanation is accepted as fact. Unfortunately it is one of those statements which have no foundation whatsoever.

When the negative is developed there are certain silver grains which will stick together, just as grains of sand will cling together when moistened. But we must also remember that when two grains touch, both are developed even if only one was exposed. Thus if the gelatin is attacked we often have long crooked

chains of grains developed when only one of them was really exposed. The physical appearance of such a condition might be likened to several dozen strings of beads dropped carelessly upon a table. Even the beads of the string are not made up of single grains, but of several grains clumped together. So we can see that

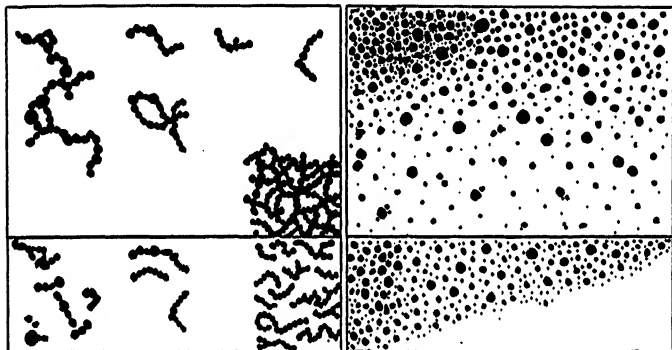


Fig. 16. Grain chain formation. Top, a view looking through the emulsion; below, a cross-section.

Fig. 17. Isolated grain pattern; decreasing depth of grain accompanies decreasing density.

the microscopic grains through third-degree bunching together will become large enough to produce an image even at moderate enlargement. Even so, these bunches and strings are not the true origin of the graininess in the print.

Figure 16 shows a greatly magnified presentation of grain-chain formation in the negative. The upper drawing represents a view looking through an emulsion, while the lower drawing represents a cross-section of the emulsion. At the left, above, is a complex chain, which upon examination from the side proves to be made up of six short chains and two isolated grains. At the lower right, above, is shown a complex

structure formed by many single chains scattered at various depths in the emulsion, as revealed in the cross-section.

Another illustration, Fig. 17, shows an isolated grain pattern. The upper drawing shows how much more nearly the dot pattern approaches a uniform tone than does the chain network. At the upper left there is an area of great density grading toward the right and toward the bottom. The lower drawing shows in cross-section how the decreasing depth of grain mass accompanies decreasing density.

Remember that a black spot in the print must always come from a light spot in the negative. Therefore the origin of the grain images must be spaces between silver grains in the negative. Just imagine the way in which light falls through the leaves of a vine-covered arbor and you will get a fair picture of the condition which is responsible for the graininess.

Imagine a negative in which all the silver grains remain separate. Upon projection the general light background would form a gray area in which the individual grains would produce a dusting of lighter spots. Such an area would take on a gray tone lighter than the actual background tone, but there would be no disturbing pattern. On the contrary, when the grains string out and form tangled masses we have a light gray background upon which darker spots are formed by the openings between the grain chains, and the pattern does become obvious. Even so, if the pattern is regular it is not too disturbing; but when the chains become long and tangled, there is an irregularity of distribution of the pattern and the result is a grainy print.

There is an idea that grain pattern is important only in miniature negatives, but this is a mistaken idea. Aside from studio photographers who use cameras of 8x10 size and larger, any negative is subject to pro-



New electron microscope-camera reveals thread-like structure of the developed silver grain, shown in photomicrograph above.

jection printing. Not only this, but in many cases almost half the negative is lost because there has been insufficient opportunity for composition, therefore the picture is centered and the edges of the negative are wasted. The average $3\frac{1}{4} \times 4\frac{1}{4}$ negative rarely has more than $2\frac{1}{2} \times 3\frac{1}{2}$ inches of usable area. To make the usual minimum 8x10 print this means a four-diameter enlargement, and although grain pattern may not be evident at such a degree of enlargement, the crispness of the definition and texture will be injured if there is a hidden grain pattern of objectionable quality.

It is therefore advisable to take due precaution to avoid graininess whenever possible. On the other hand, there is not a need to make use of extremely low-potential developers such as paraphenylenediamine, because such developers avoid graininess at the cost of considerable quality in the negative. Just what means may be employed to control graininess? This will be discussed at greater length in the next chapter, but at this time we may mention those factors which are related to the physical nature of the negative.

In the first place the graininess of the negative is largely an inherent factor. This has often been disputed, but the fact remains and has been substantiated by the large research laboratories. Therefore the first step is to choose a finegrain emulsion. The next step is to avoid any developer which has a definitely destructive effect upon the emulsion such as those containing caustic alkali. These developers are usually used with slow emulsions to obtain high contrast, and as such emulsions usually have a fine grain structure, the final result is not objectionable. Even the carbonate developers will soften the gelatin sufficiently to permit grain clumping to a greater degree than is acceptable for finegrain work, although it must be added that the developing agent (reducer) itself has a definite effect upon the grain structure. Pyro, for example, with its

potential of 16, gives an excellent pattern as a rule. The developer choice, therefore, should be in the direction of the ones using a milder alkali, such as the borax types of developer. With these developers metol and hydroquinone are retained for their excellent image-forming qualities. The borax negative is characterized by an excellent gradation, full density, and regular grain pattern. Except for the extreme degrees of enlargement, the borax negative will be found quite satisfactory.

It is obvious that the greater the number of grain chains which are superimposed in various strata of the emulsion the greater will be the chance for apparent clumping. That is, the large clumps do not actually exist, but several smaller clumps in superimposed strata may lie in positions which, when looking through the negative, give the impression of an actual large clump. For this reason it is advisable to keep the exposure to the lowest level which will produce a good image. The absence of overexposure will prevent excessive chain formation in the deeper strata, and give the negative as a whole a grain pattern more in keeping with the actual grain distribution.

Another factor is the maintaining of uniform temperature. If you stick a piece of sponge rubber full of needles and then compress the rubber in various directions the needles will work around through the rubber. Likewise if you have a sheet of soft, flexible gelatin filled with metallic grains, the kneading process which results from the contraction and expansion of the gelatin under different temperatures will push the grains into contact, and once they are in contact they usually remain. Therefore, a uniform temperature produces a static gelatin condition, and this is a decided help in the prevention of grain clumping. This subject of grain in the negative will be discussed further in Chapters V and VIII.

Resolving Power.

Closely allied to graininess is the resolving power of the emulsion. If you have a pattern of fine lines drawn closely together so that they are separated by white stripes just as wide as the black lines themselves, you will have a test object. It is obvious that as this pattern is removed farther and farther from the camera the image will become smaller and smaller, until finally the lines will no longer be photographed as lines, but the whole area will take on a medium gray tone. This is the limit of **resolving power**—that is, the emulsion can no longer **resolve** (or separate) the individual lines.

We must remember that the line image is not a line, but a very narrow streak made up of a large number of silver grains. If there are excessive chain formations the line will not be sharp, but will be ragged just like an ink line drawn upon a bit of newspaper stock. While this may not be visible in its true form, it will prevent the line from appearing sharp. Therefore we can see that although we may have an objectionable grain pattern, the image will probably suffer even more from loss of sharp definition; in fact we may have a print which lacks definition yet in which the graininess is not visible as such.

Fig. 18 shows one type of chart used for testing resolving power. The central arrow of the original is $1\frac{1}{4}$ " long, and the calibrations along the top and bottom indicate a decreasing thickness of the arrow in single millimeters. The calibration at the side is a centimeter scale for judging changes in size from the original. This chart is set up at any convenient distance and a photograph made. From the negative a contact print is made which will show the size of reduction by measurement on the centimeter scale. Next an enlargement is made of sufficient size to show the

loss of separation of the lines near the arrow point. The width of the line at this point is measured, and the result is the resolving power. For example, if the contact print shows the copy to be $1/100$ the size of the original, and the lines merge at the 3 mm point, then the result shows that the limit of resolving power

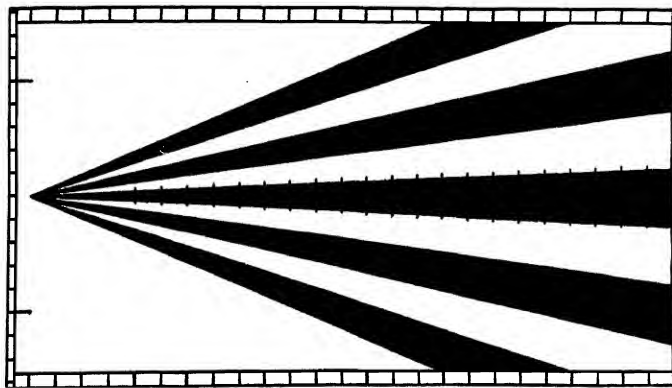


Fig. 18. One type of chart used for testing resolving power.

of the emulsion is 3 mm divided by 100 (the scale of reduction) or 0.03 mm, which is about $1/800$ inch.

Resolving power and graininess are closely allied, but there are still other factors in resolving power. For example, there is never an abrupt termination of density at the edge of a sharp line, but the edge is "feathered," that is, it has a zone of decreasing density which is considerably wider than a sharp edge would be. This happens even when there is no physical contact between grains. One cause is irradiation; the light entering the emulsion is partially reflected from one grain surface to expose a separate but adjacent grain.

Again we must remember that the lens also has a

limit to its resolving power, but ordinarily the limit imposed by the emulsion is encountered long before the limit of the lens. This is shown by the fact that when the resolving limit is reached when using ordinary film, the same camera and lens will show a much greater resolution when a slow, finegrain, contrasty emulsion is used. Resolving power is important, and while the rule is by no means absolute, it is found under average conditions that resolving power increases as the sensitivity or "speed" of the emulsion decreases.

A word of warning should be given here. There is entirely too great a tendency on the part of advanced amateurs to blame their failures upon the poor resolving power of the emulsion (or some other technical factor), when in fact the trouble is nothing more nor less than blur caused by their own carelessness.

No test of resolving power can be considered as having any meaning unless: 1, the quality of the lens has already been tested; 2, the lens is used at a moderate aperture; 3, focusing has been done with the utmost care using a magnifier for the purpose; 4, the registration of the mechanical focal plane with the optical one has been tested and proven; 5, the camera is fastened firmly to a tripod so heavy that it cannot be made to tremble; and 6, the exposure has been somewhat more than merely reasonably accurate.

Just bear this one fact in mind when making tests; be sure that everything which has the least effect upon the result, or which could possibly have such effect, is of definitely known characteristic or quantity. Leave nothing to chance, or your test results will be worthless.

The Negative Image.

The qualities of the negative which we have discussed, its reactions with the developer, and the char-

acteristics of the developer itself all lead but to one thing—the final negative image. The inherent qualities of the emulsion and the influence of the developer are worthless except as their final result affects the latent image impressed by the exposure. We know, of course, that the exposure must precede the development, but too often the intimate relationship between the exposure and development is lost sight of.

There is an old, old rule which says "Expose for the shadows, develop for the highlights." That rule under various guises has been handed down through generations of photographers. Its continued existence is due in part to its fundamental truth, but too often it is interpreted as meaning that there is only the most casual relationship between exposure and development. This is not at all true. Again we often hear "When the exposure has been made, the image is fixed beyond alteration by development." This is also very true, yet untrue! The whole trouble lies in the fact that we only half interpret such statements.

For example, suppose we make an exposure in which the shadow detail is barely recorded in the latent image. Now it is perfectly true that we cannot develop any more shadow detail than the exposure has recorded. But if we develop in a low-potential developer, such as hydroquinone or paraphenylenediamine, we will fail to get an image at all in these shadows. Now the mere fact that one developer can bring out detail in shadows which is not produced by another developer is not a sign that the more energetic developer is bringing up details which were not recorded; it simply means that the low-potential developer is not doing the fullest possible work.

Again we are told that for paraphenylenediamine developers we should give two to four times the normal exposure, because the gentle developer produces a loss of speed in the film. Again trying to put the

fault on the film! The fact is that this developer is highly inefficient and will not do the work for which a developer is used. Perhaps the words make no difference, but if you get to thinking that developers can affect inherent sensitivity or that some developers can bring up unregistered detail you will grow into a grave misunderstanding of the fundamental reactions of photography.

Therefore, when you read or hear such statements do not consider them limited by your habitual routine, but consider them as applied to fundamental photographic facts, and you will find yourself free from the confusion which confronts so many amateurs.

The foregoing example of the inability of low-potential developers to reduce the entire image, and the fact that the loss is not evenly distributed but occurs in the shadows, is an illustration of the relationship between exposure and development. How is the condition remedied? By increasing the exposure until the least intense light has affected the emulsion to a degree from two to four times as great as would be necessary if a normal developer were to be used.

On the contrary, if a roll of film is exposed and developed and then found to be underexposed, a change to a developer of higher potential will often work wonders with similar rolls, through converting what was an underexposure into a normal one. In the event that films run toward overexposure, the use of a low-potential developer will save them through its lesser activity. Here we see an example of true exposure compensation by development. The warning against this is meant in an entirely different way. You can't overcome underexposure by pushing the time to the limit in the same developer, just as you cannot overcome overexposure by shortening the time of development.

Because of the compressed tone ranges at the toe

and shoulder of the characteristic curve, and because a negative lacks contrast in the early stages of development, many amateurs believe there is an irregular rate of density growth during development. This is not true. The rate of growth is proportional to the time of development. That is, during the period required to

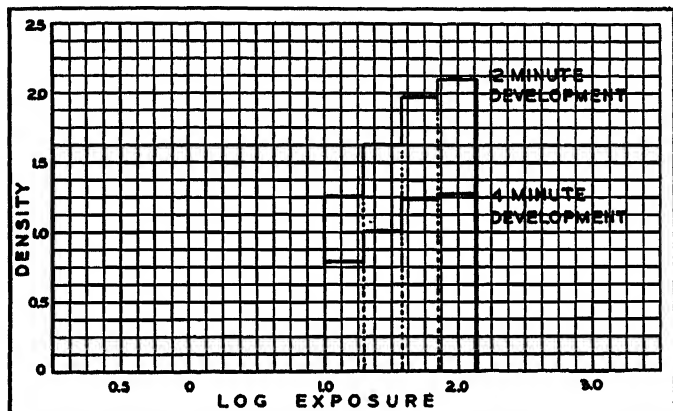


Fig. 19. Diagram showing the relative increase in density during four- and twelve-minute development for four exposures.

double the density of any one tone, any other tone will also have doubled in density.

For example, suppose there is a shadow area of density 0.1 and a highlight area of density 1.0 during an early stage of development. The ratio between these two densities is 1:10. If, at a later stage of development, the shadow density grows to 0.2, the highlight area will have grown to 2.0—still a ratio of 1:10. However at the early stage the actual transmissions of the two were 98 and 10 per cent respectively, or 9.8 to 1, while in the second case it was 95 and 1 per cent, or a ratio of 95 to 1—an increase of almost ten times,

although the proportionate growth has remained the same. Figure 19 shows the relative increase in density during four and twelve minutes of development for four exposures.

In the ultimate printing we are concerned with the absolute density differences rather than the relative ones. Thus if we have a negative which shows a range from 0.06 in the shadows to 3.0 in the highlights, a tonal range too great to print, we can cut off two-thirds of the development time, thereby reducing the densities to 0.02 and 1.0, respectively—a range which is easily printable. This is the basis for compression development to control subjects of originally high contrast.

When the image starts to develop, all the detail is more or less visible. After that the highlights build more rapidly than do the shadows, so that there is a constantly increasing contrast in the image. We must therefore always keep in mind that a given emulsion developed in a given developer will grow in contrast as the time of development is prolonged. But note that changes in film, in emulsion, in developer composition or concentration make the rule void; only when applied to a given set of conditions is the rule necessarily true.

It is true that under a given set of conditions there are definite results to be expected from under- and overexposure as well as from under- and overdevelopment. Referring to the early part of this discussion we saw that a quantity of light smaller than is required for the full exposure of the emulsion throughout its depth will expose a certain proportionate part of the emulsion, which exposed portion may subsequently be developed. It was also learned that a certain minimum exposure is necessary to produce any effect whatsoever. With these two points of departure we may investigate the mechanism of exposure plus development.

Exposure and Development.

When any ordinary scene is photographed, the range of light intensity in that scene will usually take up the full capacity of the emulsion to handle under- and overexposure. That is, the shadows will be barely strong enough to make the faintest impression, while the highest intensities will be strong enough to expose the emulsion throughout its depth. It is obvious that to match the range of light intensities to the potential range of the emulsion, the exposure must be controlled with reasonable exactitude. When this is done the developed negative will show the faintest trace of silver deposit in the deep shadows while the highlights will have full density.

Assuming that such a scene is available, we shall further assume that nine films are exposed with this scene as the subject. Three of these will be underexposed, three will be correctly exposed, and three will be overexposed. When these films are to be developed they will be divided into three sets, each set containing one each of the test exposures. One set will be underdeveloped, one set will be normally developed, and one set will be overdeveloped. Now if we use the code letters U for under, N for normal, O for over, E for exposure, and D for development, we can arrange the set of nine negatives, after development, in this manner (Fig. 20):

	Under- exposed	Normally Exposed	Over- exposed
Underdeveloped	UE-UD	NE-UD	OE-UD
Normally developed ...	UE-ND	NE-ND	OE-ND
Overdeveloped	UE-OD	NE-OD	OE-OD

It will be noticed that the central negative, NE-ND, is the only one in the nine which may be said to be correctly handled throughout. Taking these nine nega-

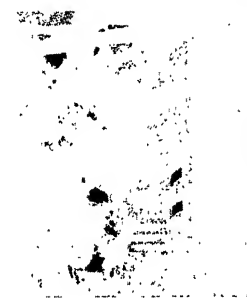
EXPOSURE AND DEVELOPMENT

UNDEREXPOSED

NORMALLY EXPOSED

OVEREXPOSED

UNDER-
DEVELOPED



UE-UD

NE-UD

OE-UD

NORMALLY
DEVELOPED



UEND

NEND

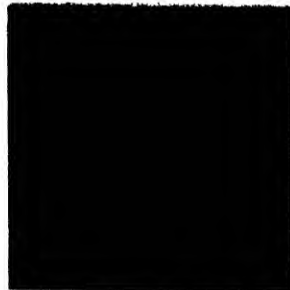
OEND



UE-OD



NE-OD



OE-OD

OVER-
DEVELOPED

Fig. 20. The left-hand column of negatives received an exposure about one-fourth normal, the center column was normally exposed, while the right-hand column received four times normal exposure. The top row received one-third normal development, the center row was normally developed, while the bottom row was given three times normal development. Code letters appearing under negative refer to their exposure and development; characteristics are discussed in text.

tives one by one, we should expect to find the characteristics as listed in the following paragraphs.

UE-UD. The underexposure will have failed to register shadow detail, so the shadows will be blank. The highlights, unless unusually brilliant in the original, will not be of full density but will be obviously thin because there has not been sufficient development to bring them up to full strength even though they were fully exposed. In any exposure error, the error usually extends only to one set of values. In underexposure the shadows are underexposed but middle tones and highlights are not. In the normal negative all shadows have actually been underexposed and all highlights have been overexposed. Thus it is possible to have fully exposed highlights in an underexposed negative.

NE-UD. This negative will show detail in the shadow except for the extremes of deep shadow. This shows that the necessary exposure has been given. At the same time the highlights will be of too low density, showing the lack of complete development. This will be a soft or flat negative, i.e., one lacking in proper contrast. If the underdevelopment is serious there may be patches showing varying degrees of development.

OE-UD. This negative is typical of the attempt to salvage a known overexposure by removing it from the developer too soon. There will be full detail in the deepest shadows, while the highlights are but slightly darker than the shadows. The entire negative is heavy and almost too opaque to reveal the image when examined by transmitted light. Such a negative should be developed to full strength and then submitted to the action of a reducer. Fig. 21 shows a print from this negative.

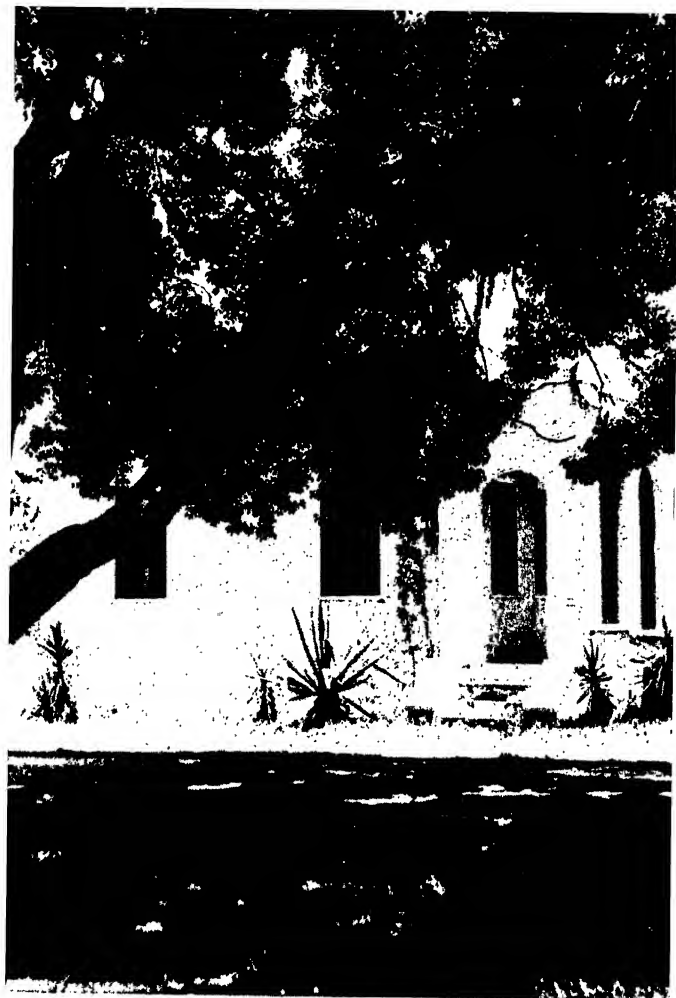


Fig. 21. Extreme contrast is lost in print from OE-UD negative. Shadows indicate brilliant sun; highlights suggest a hazy light.

UE-ND. This negative will show blank shadows, but the highlights will be full strength. This produces an impression of excessive contrast and may be called overdevelopment. However, the absence of shadow tones and the full strength highlights tell the story of underexposure. Such a negative will actually print better if it has a deposit of uniform fog.

NE-ND. This is the most difficult negative to describe. There should be a delicate but definite record of detail in the deep shadows. There should also be unmistakable detail in the highest light. For example, a photograph of a girl wearing a white dress should show the folds, the seams, and other details of the white dress. The highest light should be just dark enough that when the negative is held up before a newspaper (not laid upon it), the paper can with some difficulty be read by looking through the highlight. This is a crude test but one easy to apply (See Fig. 22).

OE-ND. This negative resembles the preceding one at first glance, but examination shows the shadow details are too strong, the highlights practically opaque, and the entire negative has a heavy, blackish appearance. The normal negative has an unmistakable delicacy of tone quality which is lacking in this one.

UE-OD. This is a beginner's negative. It seems to have but two tones—the clear base of the shadows and the inky black of the highlights. It is this “soot-and-whitewash” appearance which serves to distinguish it from the preceding two underexposures. Such a negative is practically beyond redemption, and the best remedy is to make it all over again.

NE-OD. This is the “snappy” or “brilliant” negative so well liked by the beginner. It looks a lot bet-

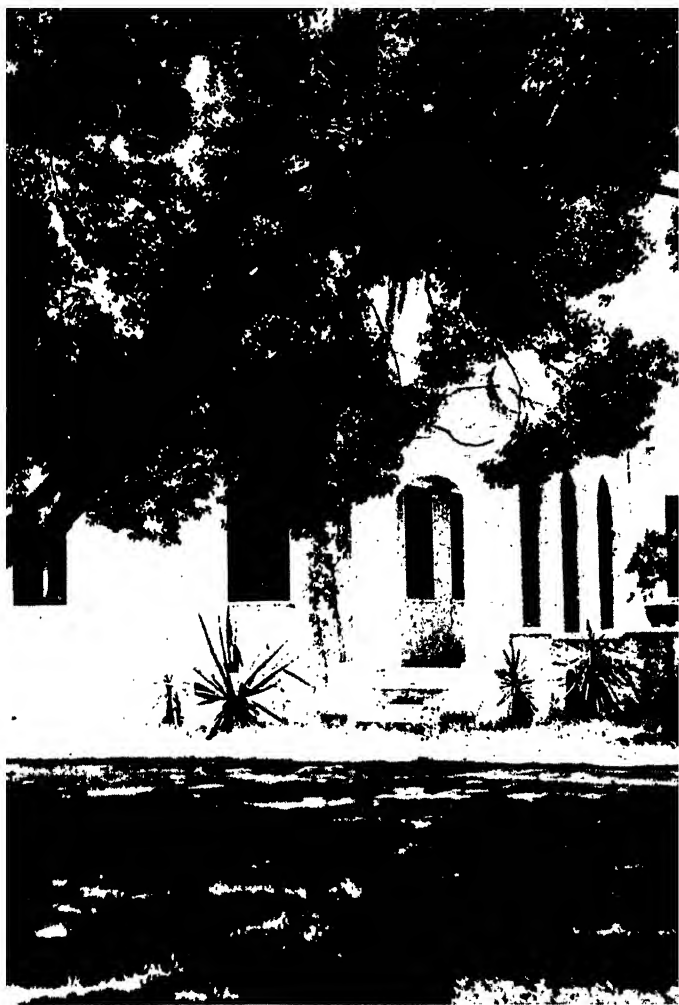


Fig. 22. In a print from the NE-ND negative, detail is preserved in both shadows and highlights unless they run into extremes.

ter than the normal negative, and the beginner can hardly believe his senses when it fails to produce a good print. The fact is that while it may be an excellent negative record of the original subject, it has a contrast range so great that it cannot be printed. Attempts to print it throw several of the shadow tones into pure black and most of the highlight gradation which produces highlight detail is blocked up and the object prints as a white silhouette.

OE-OD. This negative resembles a classic photograph—that of the black cat in the cellar at midnight! In this example the negative is thick and so uniformly black that the image can hardly be seen, much less be observed closely enough for criticism. If it were examined, the image would show that there had been an initial excessive contrast, followed by loss of contrast as the shadow detail built up far below the minimum. In this case, even with overdevelopment there is a lack of contrast because every tone in the negative, even the faintest shadow detail, is at least half the maximum density which the emulsion can produce, so that there is available only the remaining half of the normal tonal range to reproduce the entire tonal scale of the subject. (See Fig. 23.)

These characteristics can be seen by the experienced photographer. Underdevelopment may sometimes resemble underexposure so closely that without knowing the exposure conditions it would be risky to make any definite statement. Likewise overdevelopment of a fully exposed film may produce a negative which the expert would pronounce as a definite overexposure. Therefore it isn't wise to be too sure of a diagnosis until all the data are known. However, the foregoing will serve to identify the labels of the eight serious errors in the exposure-development complex,



Fig. 23. Print from OE-OD negative. Light shadow detail gives false sense of luminosity. Light tones in building are lost.

and if the amateur were to make such a set of negatives deliberately and keep them for study he would learn more practical photography than from reading a library of books or attending a lifetime of lectures.

As we shall stress from time to time, it is advisable to study in order to identify guideposts, but the actual **learning** is only done by practical experience and experiment.

If you really want to learn to make negatives, make them and learn. In our next chapter we shall leave theory behind and get into the actual procedure of developing a negative.

III

DARKROOM DESIGN, EQUIPMENT, AND TECHNIQUE

III

Darkroom Design, Equipment, and Technique

IN actual practice the production of the negative follows closely the theoretical outline discussed in Chapter I, modified somewhat by the physical characteristics of the films and the equipment. As a matter of fact, the darkroom and its equipment will depend somewhat upon the type of sensitive materials employed, so perhaps these should be classified.

There are several ways in which sensitive materials can be grouped, the first being the physical form of the loading unit itself. In this grouping there are four major divisions, with rolls subdivided into two classes. These divisions are:

A. Rollfilms.

1. Paper-backed "cartridges."

2. Unbacked rolls (35 mm, for example).

B. Filmpacks.

C. Sheet film (also called cut film).

D. Glass plates.

In addition there are the rarely used paper sheets for

making negatives to be printed by indirect projection.

Film Characteristics.

There was a time when glass plates and sheet films were used for all serious work simply because the roll and pack forms were limited to one orthochromatic emulsion, and not a very good one at that. Today, rolls are manufactured in such variety that only the highly specialized job demands some emulsion not obtainable in that form. Therefore the choice of film, as to roll or sheet form, is one based largely upon the actual physical form rather than upon photographic characteristics.

Rollfilms. The rollfilm consists of a ribbon of sensitized film attached at one end to a paper strip which is as wide as, and considerably longer than, the film, as shown in Fig. 24. This length of film is mounted upon the paper strip in such a position that index numbers on the reverse of the paper act as guides in advancing the film for successive exposures.

Eastman films have a gummed paper tab attached to the free end of the film. When the old type of Eastman developing tank is used, the exposed film is unrolled carefully in the darkroom until this tab is reached. The gummed edge is moistened, and the film re-rolled. This attaches both ends of the film to the paper, so that the whole thing may be wound into the rubber apron of that type of tank. In moist climates this tab sometimes attaches itself to the backing paper while in the camera, and the film cannot slip along the paper to compensate for the change in diameter when passing from one spool to the other. This produces a hump at the end of the roll which causes the camera to jam.

Because the leading end of the film is attached and the trailing end is free, films cannot be fed through



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Fig. 24. Rollfilm consists of a ribbon of sensitized celluloid attached at one end to a protective strip of opaque paper.

the camera backwards. This is attempted at times when a roll is wound past the starting point, or for some other reason the first of the roll is not exposed. In such cases the whole roll should be wound through the camera; then in the darkroom or changing bag it is re-rolled to its original position and inserted into the camera as before.

The rollfilm is undoubtedly the most convenient form of film available. The rolls are easily carried, and when using a modern tank the entire roll is fed into the rack in a single operation. The form of the film makes very unlikely any over-lapping in the tank which would prevent development. Modern emulsions are of such high quality that just as good work can be done on the roll as upon any other type of film.

The rollfilm camera usually has a metal pressure plate built into the back. Its purpose is to press the film against the limiting aperture which frames the picture, and thus hold the film flat against this aperture in the focal plane of the camera. When a considerable time elapses between exposures, and the film is wound immediately after each exposure, the film may "bulge" into the aperture, making the center of the film nearer the lens than it should be. This is made worse at times by the air suction produced on opening the bellows. On the contrary, in very dry climates the film may start to harden and curl in the opposite direction, forcing the film back. The springs of the pressure plate give, and the center of the film becomes removed farther from the lens than it should be. Both these conditions will result in a loss of sharp definition, particularly when large lens apertures are used.

Film should be wound into place immediately before the exposure. It is just as easy to form the habit of winding before taking a picture as to wind immediately afterward. Some cameras operate in such a

manner that the film is automatically advanced as the shutter is set. Thus the winding usually takes place just before the exposure. Another objection to the rollfilm (and the only really valid one) is the fact that all the exposures are on a single film and there is no guide for cutting them before development. The remedy, of course, is to plan the sequence of pictures so that exposures on a single film do not require any differential in development.

None of these objections is serious, as shown by the fact that the majority of good photographs taken by amateurs, even including salon negatives, is made on rollfilm. Because of its thin base this film is not convenient for handwork, particularly retouching and etching, but these are operations usually confined to the larger negatives anyway, so again the objection is hardly a valid one.

Filmpacks. The filmpack is a package of films of the same general type as rollfilm, but in which each film is cut to size and attached to a paper backing. This backing has a long tab which extends outside the pack and serves to pull the exposed film from its position in the front to the back of the pack where it remains until removed for development (see Fig. 25).

The pack film is so thin that it often buckles in the usual sheet-film tank. It is best developed in a deep tank, using a special hanger, or in a tank whose film-holder has curved grooves. The pressure within the pack must be strong enough to compensate for the loss of thickness occasioned by the removal of the twelve pulling tabs. At times this will cause the first few films to bulge into the camera. However, it is only fair to say that I recently saw a one-shot color camera using filmpacks without pressure plates, and a three-diameter enlargement did not seriously affect registration; so this bulge is more serious as a point of theory than of fact.

Exposed films may be removed from the pack for development at any time without disturbing the remaining unexposed films. Individual films may be given individual processing, and for that reason the pack is favored by many photographers. It is not, however, available in as wide a variety of emulsions

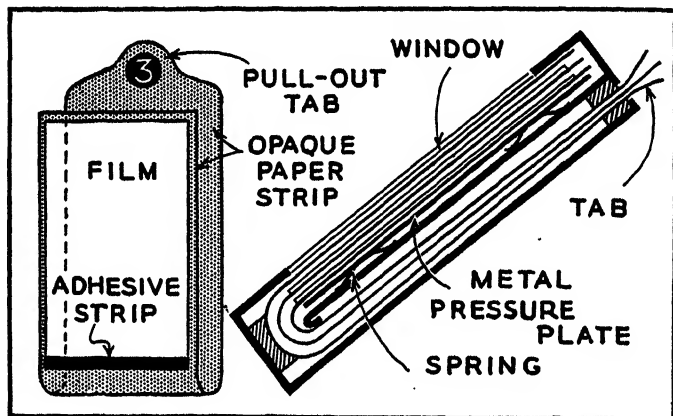


Fig. 25. Left, one of the film units from a film pack; right, a cross-section of the pack, showing pressure plate and springs.

as is the rollfilm. The film pack is made primarily to provide the convenience of a quantity of material in small space, and adapted to cameras normally using glass plates or sheet film.

Sheet Films. Sheet films were sold half a century ago under the name "celluloid plates." That is an apt name for them when speaking to any of the old-timers, but the present generation of photographers rarely uses plates, and the film is the standard. Sheet film is cut to a definite size, after the comparatively heavy stiff celluloid base has been coated with the emulsion. It is loaded directly into special holders or magazine

septums; or used in holders designed for glass plates, through the medium of special kits or sheaths.

This film is the professional type of sensitive material. It is available in a wide variety of emulsions, is easily handled and processed, is handled as a unit in all steps, and usually has a richer emulsion than rollfilm and film packs. The sheet film requires dark loading, either darkroom or changing bag, and the holders are considerably more bulky than the rollfilm cartridges, even when a magazine is used. It is the material usually used by the more serious workers with plate-back and larger view cameras. It may be retouched or etched easily, and with reasonable care against dust and fingerprints may be handled freely because of the stiff body of the base.

Sheet films may be developed in most plate tanks, but modern tanks made especially for this film are preferable.

Glass Plates. Glass plates are like sheet films, except that the base is glass instead of celluloid. They are not widely used at present outside of professional studios, but some color workers insist upon using the plate because it will give accurate registration. In all cases where absolute linear accuracy is necessary, as in reproduction and similar photographic work, plates are commonly used. Some amateurs still prefer them for copying and for photomicrography. However, they are limited in use to the photographer who does highly specialized work, and for that reason we need not consider them any further. They are a specialty for specialists, although the oldest type of sensitive material we have.

For the traveler, the casual amateur, the pictorialist—in short, for everyone to whom size, weight, and bulk are important—the rollfilm is probably the most practical film. For the still life and studio worker, naturalist, press photographer, and specializing ama-

teur the sheet film is probably more widely used, with filmpacks filling in when many shots in small bulk become necessary. The plate is too highly specialized for consideration on our part.

Color Sensitivity. The second film characteristic is that of color sensitivity. Ignoring the many subdivisions for the moment, we have color-blind, orthochromatic, and panchromatic emulsions. These classes are not sharply divided, but overlap. Some color-blind emulsions may be handled freely in an orange light while others would fog. The same thing applies to orthochromatic emulsions; some may be developed by red light while others are definitely sensitive to it. So we find that color sensitivity is based upon a continuous scale which we arbitrarily divide into three groups. If the film is sensitive to blue and violet but not comparably sensitive to green, yellow, and red it is called color-blind. This includes the positive and process types of emulsion. If it is sensitive to blue, green, and yellow but not comparably sensitive to red it is called an orthochromatic emulsion, while if it has such sensitivity to all visible color that will record in an ordinary exposure, the emulsion belongs to the panchromatic group.

There are subdivisions, of course. A panchromatic film may be far more sensitive to blue than to green or red. It may be extremely sensitive to red, but only slightly so to green, and so on. It is just as important for the photographer to know these differences in reaction as it is for him to know whether the film is ortho or pan. This information is given in the color response curves which we will discuss in a later chapter.

Film Speed. The third film characteristic is that of sensitivity, or more popularly, speed. There is an idea prevalent that the quality of any film is denoted by its speed. On the contrary there has never yet been a time when the fastest film available was the best one.

If this were true the intermediate films would disappear from the market!

There are many ways in which film speeds can be rated. The original ratings are meaningless, because a name became associated with a certain sensitivity and when faster films were produced the names could hardly be changed. Therefore, we have such a paradoxical scale as: Slow, Medium, Rapid, Ultra-rapid, Par, Supersensitive, Moderate speed, Super press, Extreme speed. Obviously a scale in which "Moderate" is slightly faster than "Supersensitive" and much faster than "Ultra-rapid" is too complex for ordinary use. Some system of numerical rating is necessary, and these systems will be discussed fully in the chapter on sensitometry.

In order to establish a working basis it might be said here that the so-called **H & D System** is not satisfactory because it indicates the point at which the negative starts to react, and is based upon development, so there is a wide variation in H & D ratings for emulsions of one speed class. The **Eder-Hecht** and **Scheiner** systems are subject to manipulation. Scheiner ratings of 20, 23, 26, and 29 can be applied to the same film. The **DIN** system is subject to the same distortion. The **Eastman** comparative ratings are good for ordinary work. A new system recently published by the American Standards Association is undergoing a trial and therefore may not be approved for some time. The system introduced by **Weston** for use with their meter is satisfactory for specific exposure control, so we shall consider sensitivity in terms of Weston ratings. General Electric also introduced their own system of sensitivity rating, but it has not been as universally accepted as has the Weston system, which many authorities regard as the unofficial standard for this country.

Film Coating. We may also consider films in re-

gard to the method of coating; 35 mm films and some sheet films are coated on one side only. Roll and pack films and some sheet films are coated on both sides, the rear coating of plain gelatin serving to prevent excessive curling of the film when drying. The film may have a colored back coating to prevent halation, or it may have a subcoating of color for the same purpose. It may have a special coating designed to produce a matte surface which adds to printing quality and facilitates retouching with pencil.

All these film characteristics affect the process of development to some degree and must be taken into consideration. For example, color-blind and ortho emulsions may be developed in a room lighted by a safelight. The light, to be safe, must have a color to which the film is not sensitive. Color-blind film emulsions may be developed in an orange-red light, while ortho films must be developed in deep red light. Some panchromatic films are developed in green light because the film is not very sensitive to green, while the eye is highly sensitive to this color. This light is not really safe, but when very dim and the film exposed only briefly it can be used. Most of the modern, fast panchromatic emulsions must be processed in total darkness.

Fast emulsions of a given type usually require more development than slower films of the same type; but modern supersensitive films require no more development than the old type of supersensitive, which are only one quarter as fast. Thin base films, such as rolls and packs, require more stable support in development, or require wide spacing to prevent buckling and sticking together. Therefore the film which is to be developed will affect the process of development to greater or lesser extent. There are, of course, standardized universal methods of development, but they do not necessarily produce the utmost possible negative quality.



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The safelight is tested by placing a partially covered film about a foot beneath it for 30 seconds. The light is safe if no visible fog appears on the exposed portion after development.

The Darkroom

Before you attempt to develop your films, the necessary equipment must be obtained. This will be selected by consideration of (a) the chosen methods of development, (b) the investment to be made, and (c) the darkroom space available. Because this is true, we shall first of all consider the darkroom.

A special room for this purpose is not necessary. The kitchen, the bathroom, or a spare closet may be pressed into service. Apartment dwellers often prefer to join a camera club and make use of club facilities, but the personal darkroom, even of the simplest kind, is preferable to most photographers. When prepared developing solutions are used, and the films are developed in a tank, the entire outfit takes up very little space and may be kept in a box the size of a small overnight bag. Even the darkroom may be dispensed with if a changing bag is used.

The **changing bag** is a black bag made of several thicknesses of opaque cloth or rubberized material. It has one open end which can be closed with snaps, and at the corners of the closed end short sleeves with elastic cuffs are attached. The film and tank are placed in the bag and the end closed. The hands are inserted into the sleeves, and the tank loaded inside the bag by "feel." This gadget is invaluable to the amateur who lacks space for a real darkroom. Without it he is limited to working at night.

Residents of modern apartments often find space so limited that it is impossible to make use of either the kitchen or bathroom even as a temporary darkroom. The laboratory cabinet has been designed expressly for the use of people in such circumstances. Although one or two such cabinets have been placed on the market, they are usually built to the order of the user according to his own preferred design. The

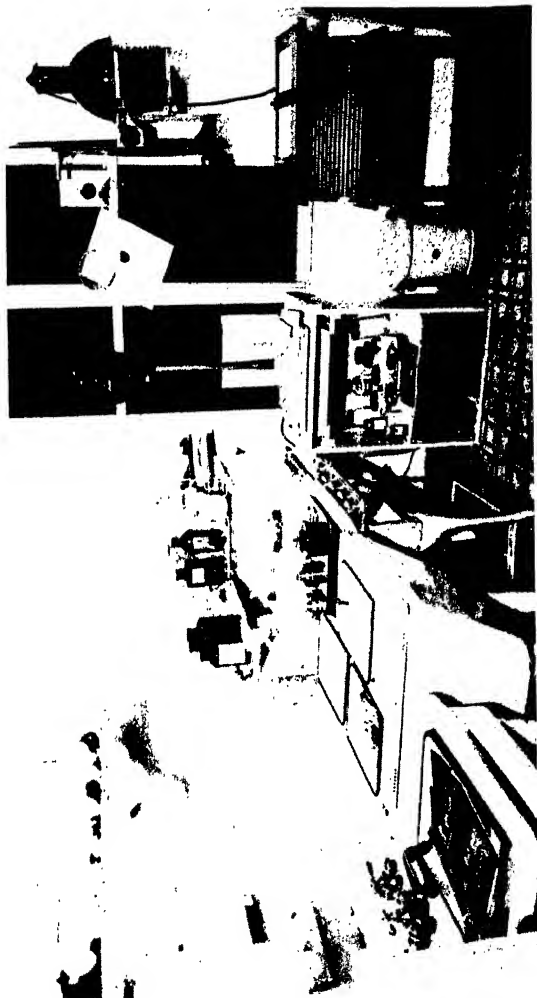


Photo by Morris Germain
The kitchen may be transformed into a temporary darkroom by using equipment that can be set up and taken down easily.



Photo by Morris Germain
The bathroom lends itself to use as a temporary darkroom.
Plan carefully so as to make the most of available space.

unit looks somewhat like a miniature kitchen cabinet, being approximately 24 by 36 inches in size and of table height. A cabinet is attached to the back of the table surface; it is about 8 or 9 inches deep and 24 to 30 inches above the top of the table. Two folding leaves attached to the table top may be unfolded to make the working space approximately twice the length of the top when closed. The only objection to the use of such a cabinet is the fact that it must either be moved into a room where there is running water, or water must be carried into the room in any convenient vessel.

One cabinet design has the enlarger mounted on the inside of one of the upper cabinet doors, which is swung open to bring the enlarger into place. Another type of cabinet has a contact printer set in a sliding shelf, which can be pulled out for use. The cabinet is simply a convenient storage space for the equipment and materials used in photography, plus a working table. Although extremely convenient in cramped quarters, it is not advised except in an elaborate form, because there is insufficient room, no continuous water supply, and unless very heavily built it is not sufficiently rigid for satisfactory use.

The basic requirements for any darkroom, permanent or temporary, are total darkness, running water, and ventilation. A room where the windows let in the light from neighboring apartments, from street lamps, or from the flash of passing auto headlights, is not dark; neither is one which lets stray light beams leak in through cracks around a door. The darkroom must be dark. However, if stray light is totally excluded, the walls of the darkroom may be of light color to very good advantage. The finest darkroom available would be one lined throughout in green or gray-green tile. The idea that a darkroom must have black walls dates from the old darkroom where light was excluded sim-

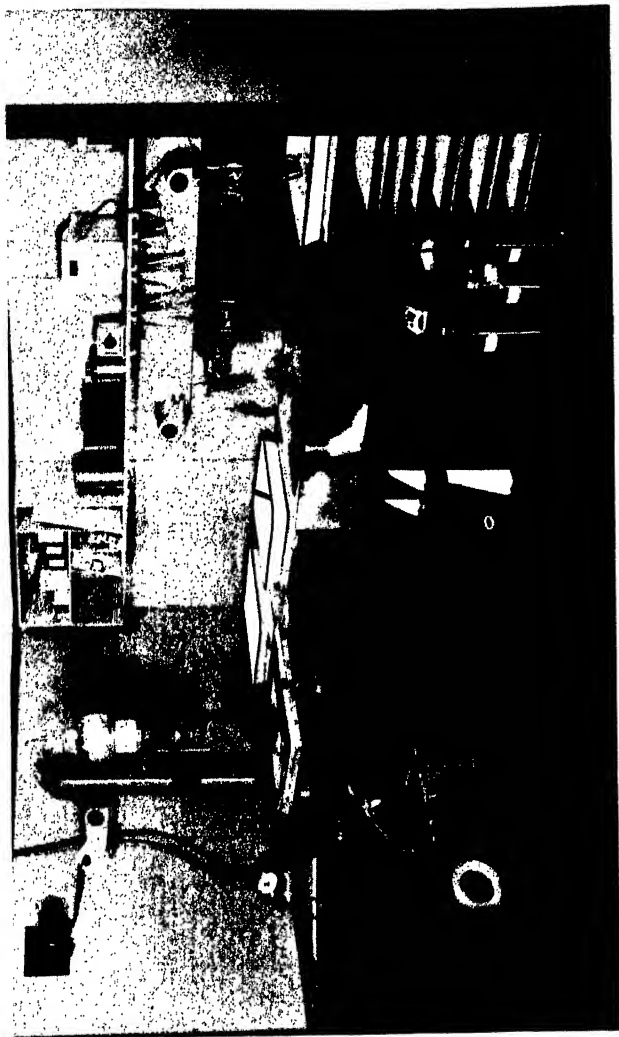
ply by a winding corridor, which with light walls would lead light in through multiple reflection.

Running water is not absolutely necessary, but to work without it is to work under a serious handicap, for hands should be rinsed in running water every time they come into contact with any of the processing solutions. This is not for the protection of the hands, for most photographic solutions are harmless, but to protect the films from accidental marks in handling. Moreover, negatives (and prints as well) should receive a rinse in running water between developer and hypo.

Most of the ill effects of darkroom work result from lack of ventilation, particularly if one smokes in the room. An unventilated room soon gets damp and musty, and good work is almost impossible. Of course if the bath or kitchen is used for occasional work, the water and ventilation are taken care of already, and with a little care these rooms may be made light-tight if the work is restricted to night. However, it is the dream of most amateurs to have a permanent darkroom.

The permanent darkroom should never be located in the attic; it is too cold in winter and too hot in summer. The best location is in the basement. It doesn't require very much in the way of either money or labor to wall off a sufficiently large space in the basement and, to make it even better, to line it with a washable, imitation tile paper. The greatest cost will be for plumbing; but if there are laundry tubs in the basement, they can at times be converted for darkroom use. Even the apartment dweller often can arrange for a small room in the basement where he can do his work, particularly if two or three amateurs in the same building share the small rental fee usually charged. I have had the use of a convenient basement room for three dollars a month.

The amateur who owns his own home may have a



Eastman Kodak Co.

A highly efficient amateur darkroom can be built into a comparatively small space. This general arrangement can be followed even though alteration of size or shape is necessary.

house with a semi-finished or finished basement, and here is the best place for his darkroom. If the house has no basement, a small room on the first floor may be used, or in some cases a portion of the garage is walled off for the purpose. Almost any room can be used provided it does not run to extremes in tempera-

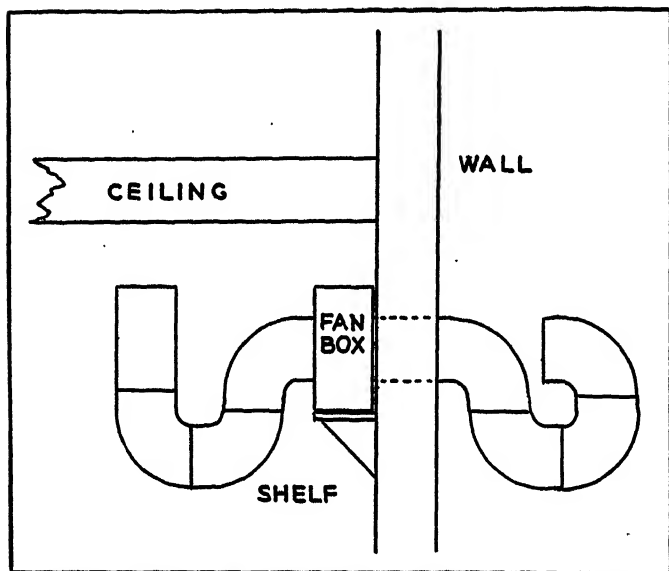


Fig. 26. Darkroom ventilator made of stovepipe elbows and fan.

ture, that it has running water, and that it is not less than six feet square. A closet smaller than this cramps the worker, and if unventilated soon gets very stuffy. Ten by twelve feet is about as large as is ever needed even for the most elaborate darkroom, although many amateurs also have a lighted workroom for spotting, trimming, mounting, and other incidental chores.

Ventilation of the Darkroom.

The problem of ventilation is one which seems to stump many amateurs. The easiest way to do this is to buy six or seven stovepipe elbow-joints and a cheap

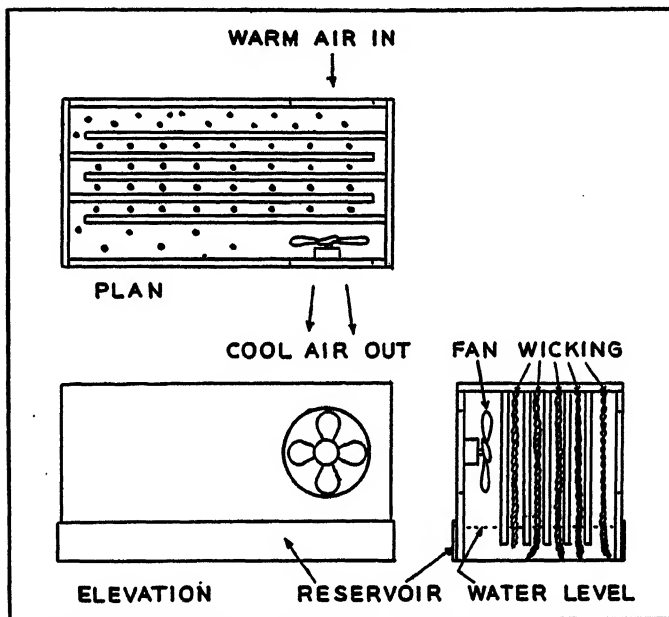


Fig. 27. Design for a darkroom ventilating and cooling box.

electric fan. Get a tinsmith to make a tin box just large enough to hold the fan, and provide it with a collar on each side to take the pipe. Make a complete "U" curve of two elbows, then add a third to join this "U" to the fan box. The open end of the "U" points upward. Set the fan box on a shelf near the ceiling and make a hole in the wall just large enough to pass

the pipe. Make a second "U" and join it to the box through the hole in the wall, then paste up any light leaks with heavy gummed tape. A switch extending through the box will control the motor. The fan will provide forced exhaust, and the double "U" with the fan between will keep out stray light (see Fig. 26).

Somewhat more elaborate is the commercial ventilator which provides free air movement through bent vanes arranged so that light will not pass them; but even with such a ventilator the fan is very helpful.

If the room chosen is necessarily in a place where the temperature rises too high for good work, a water box in the window will help. This box is made light-tight by baffles running almost from end to end, with the baffle fins joined alternately to the two ends. Here, too, a small fan provides circulation. The bottom of the box forms a reservoir for water, and suspended from the top, hanging between the baffles are lengths of candlewicking which reach the bottom and take up water from the lower pan by capillary action. The air taken in through these wicks is cooled and moistened. Used in conjunction with the ventilator it forms a fair air conditioner (see Fig. 27).

Layout of the Darkroom.

The sink in the darkroom should be large enough to accommodate two 8x10 trays side by side; this is the minimum. The best sink for amateur use is a lead-lined wooden sink (or monel metal if your inclination and pocketbook run that way). It is at least twenty-two inches wide, thirty-six inches long (forty-eight is still better), and not less than eight inches deep. It has an open slatwork platform, commonly known as "duckboards," in the bottom or supported near the top by rails. Trays and tanks rest upon this platform, leaving free drainage from any part of the sink,



Fig. 28. The darkroom sink may be equipped with a platform made of wooden slats to provide a safe place for "wet" work.

as shown in Fig. 28. The plumbing dealer or even the junkman will often be able to provide an extra large porcelain-lined sink which will serve quite well where the special sink is not available.

The sink should be supplied with drainboards at each end not less than two feet long. The faucets may be of any standard type, although the high, arched chemical laboratory type is the most advantageous as even the tallest graduate may be set under it and hoses attached to it with ease. In this as in all other darkroom fittings, the degree of elaboration must depend upon the amount of money available. While it is desirable to have a thoroughly up-to-date darkroom, some fine salon prints have come from darkrooms where most of the construction was done by the owner and the outlay fell within the limits of a twenty-dollar bill!

The darkroom floor should be rubber, linoleum, tile, painted concrete, or some other surface which is dust-free and which may be washed and mopped. One fundamental of darkroom design is to keep the room as simple as possible so that it can be kept clean. Most amateurs use one end of the darkroom for mixing chemicals, although this should be avoided if possible. The only way to prevent contamination by chemical dust is to maintain an immaculate darkroom. An ample waste basket should be provided, and all paper and scraps consigned to it immediately when discarded.

The actual layout of the darkroom will depend upon the size and shape of the original room. If the darkroom is built by partitioning off a larger room, it is often desirable to have the sink at one end of the room with a bench running along the adjoining side. This bench can be used to support the enlarger and printer, and at the end farthest removed from the sink the bench can serve as a loading table. If the chemicals are to be mixed in this room, they should be handled

near the sink so that accidental dust will have more chance of being washed down before it does any injury.

The safelight position should receive some thought. It is better to have two small safelights than one large one. One should be directly above the sink and another where it will illuminate the enlarger. Both should have interchangeable filters to accommodate any type of emulsion being handled. For example, most positive and process films are too sensitive for the greenish-yellow safelight used with bromide papers; they require a red one. The safelight should operate by a pull-cord switch, and this cord should hang where it is easily found in the dark. A white light should be similarly arranged, but its cord should be knotted at intervals of a half-inch so that it will be recognized in the dark and there will be no accident resulting from pulling the wrong cord.

Darkroom Equipment.

Now let's give some thought to the necessary equipment. Each item should be purchased with care so that it will work into the expansion produced by later additions. We shall not consider items which have to do with printing, but will consider only the equipment for negative processing. The equipment is divided into five groups, graduated from the barest essentials to the luxury gadgets.

Column A lists the bare essentials needed for tray development by inspection. It is limited to use with color-blind or ortho films and prepared developers. It has slight practical value for amateurs who really want to do their own processing, but these same items are included in all the following classes.

Column B lists the items necessary for good routine work where ready-mixed or ready-weighed chemicals are used. However, it is sufficient for good, skilled work in developing, and will serve the amateur who

does not want to go to the trouble of mixing his own solutions.

Column C lists the equipment for the amateur who wants to make his own solutions and who is expanding his darkroom into a workroom which he can enjoy and which will be a source of pride. It contains everything necessary for complete processing of the highest quality.

Column D lists the desirable additions which are made from time to time—items which make the processing easier or more convenient. These are rarely purchased all at once, but are carried home from time to time to add to the equipment.

Column E lists the items which form the gadgeteers' paradise. Most of them are nonessential, and some of them are of questionable practical value to the average amateur; but the advanced amateur finds deep joy in their possession. He even uses them sometimes. However, most of the items in the last column are indispensable to the experimenter and researcher.

A

Graduate, 8-ounce; ordinary pressed-glass type.

3 trays, about 5x7, white enamel.

Small safelight of the "Brownie" or similar type.

B

All items in Column A.

Tanks to fit the type and size of film used.

Hangers, if not provided with tank.

Thermometer, dial type preferred.

Stirring rods of plastic or glass.

Viscose sponges or chamois skin.

Towel.

Absorbent cotton.

Glass funnel, about 1-pint size.

$\frac{1}{2}$ gallon bottle for hypo.

1 quart bottle for developer.

C

All items in Column B.
Etched graduate, 4-ounce.
Etched graduate, 16-ounce.
Balance for weighing chemicals.
5x7 safelight.
Funnel stand.
Timer.
Apron.

D

All items in Column C.
Deep washing tray, about 11x14.
Plastic scoops for chemicals.
Tongs (for intensification, reduction, etc.)
Paddle (print paddle) for same use.
Rubber gloves, surgical weight.
Mechanical or electrical tank agitator.
Mortar and pestle, 4- to 8-ounce size.
Washing tanks.
Washing hose and pressure nozzle.
Graduate, etched, 1 ounce.
Graduate, 32-ounce (or measuring jug).
2 beakers, 500 cc capacity.
1 one-gallon stock bottle.
Filter paper.
Aldine Textilex negative blotting paper.

E

Graduated pipettes, 1 cc, 5 cc, 10 cc.
Drink mixer for mixing solutions.
Hypo meter (conductivity meter).
Electric dryer.
Uniform bottle sets.
Indirect safelight.
Power washer, for forced stream washing.
pH indicator for controlling standard developers.
Filter flask and filter pump.
Wall thermometer.
Hygrometer.
Film-numbering punch.
X-ray record printer.
Densitometer.

There are certain of these items which deserve brief description. In list A the graduate mentioned may be the ordinary inexpensive pressed-glass type. It is ad-

visible that all additional graduates, particularly those of small capacity, be of the etched type as they are more accurate.

There is no particular type of safelight that is definitely better than others except in the matter of size. However, the Eastman and Agfa safelights are very widely used because a number of different filters is available for each type, and these filters are scientifically prepared to combine the greatest possible safety with the greatest possible illumination. The Brownie safelight is satisfactory for small darkrooms, but when the room has forty square feet or more of floor space the 5x7 or even the 8x10 safelight is advisable.

The tanks mentioned in Column B may be of any type the user prefers. Many of the bakelite tanks for rollfilm are highly satisfactory, although as a point of standardization I use stainless steel tanks for all sizes of film. The hanger mentioned (see Fig. 29) is used only with open tanks for developing filmpack and sheet film. Closed or daylight tanks are supplied with some kind of reel, cage, or other film-supporting device.

The thermometer must be accurate and remain so. Thermometers of the type in which a glass tube is attached to a metal or cardboard scale are not satisfactory, because the scale may move with reference to the tube. The metal thermometer with a dial scale, such as supplied by Weston, is the most satisfactory type.

Stirring rods may be of the regular plastic or glass type, although inexpensive glass towel rods are excellent substitutes.

In Column C, the weighing balance should not be too cheap, or it will not have sufficient accuracy. The conventional photographic balance obtainable from most dealers is quite satisfactory.

The timer may be spring-driven or electrical, and should be capable of adjustment to any period between

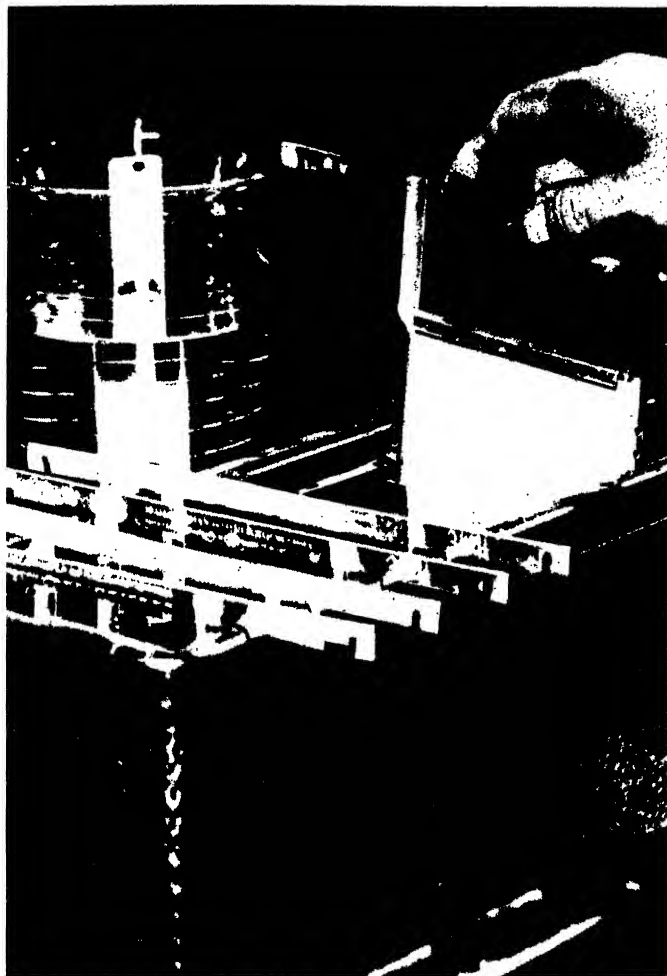


Fig. 29. Hangers facilitate the handling of sheet film during development (in an open tank), fixing, washing, and drying.

zero and thirty minutes. A greater range than this is not at all objectionable.

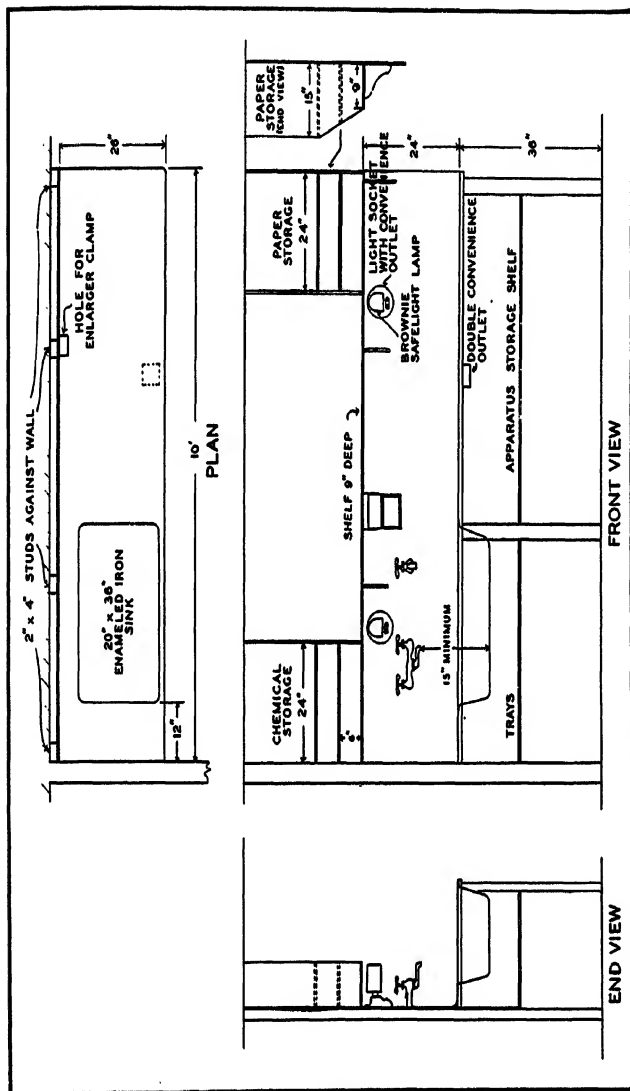
There are several items in Column D which may not be familiar. The toilet-goods counters in most stores sell miniature plastic scoops for filling compacts with face powder. These are extremely valuable for weighing chemicals in small quantities. The print paddle and tongs are ordinarily used in printing, but they are of great value in handling sheet films, and also for after-treatment of any kind of film.

Agitators are not as widely used as they should be. For uniformly good results it is essential that the tank be agitated during development. The agitator should be used as a part of the normal routine. Mortars are not commonly used by the photographer, but when small amounts of any crystalline chemical are to be dissolved quickly, the mortar is extremely convenient.

The last item in Column D is comparatively new but of great importance. This blotting paper is similar in many respects to the paper used in making tea balls. A true lintless paper which absorbs water almost as efficiently as blotting paper, it resembles parchment paper in being hard-surfaced and tough. After thorough washing, the negative is laid on a sheet of this paper and a second sheet is placed on top; a print roller is run over the sandwich with moderate pressure. When the film is stripped free from the paper, all the surface moisture is gone; not only will the film dry more rapidly, but water marks and other undesirable drying marks are largely eliminated.

In Column E the drink mixer is an ordinary home-type malted-milk mixer. It will mix a developer in cold water just about as rapidly as the chemicals can be weighed out, and is an effectual substitute for one of the most tedious steps of laboratory routine.

The hypo meter is simply a small electrical meter in series with a battery and adjusting rheostat. The



When a permanent darkroom can be built, this plan will prove very satisfactory for the principal workbench in the room.

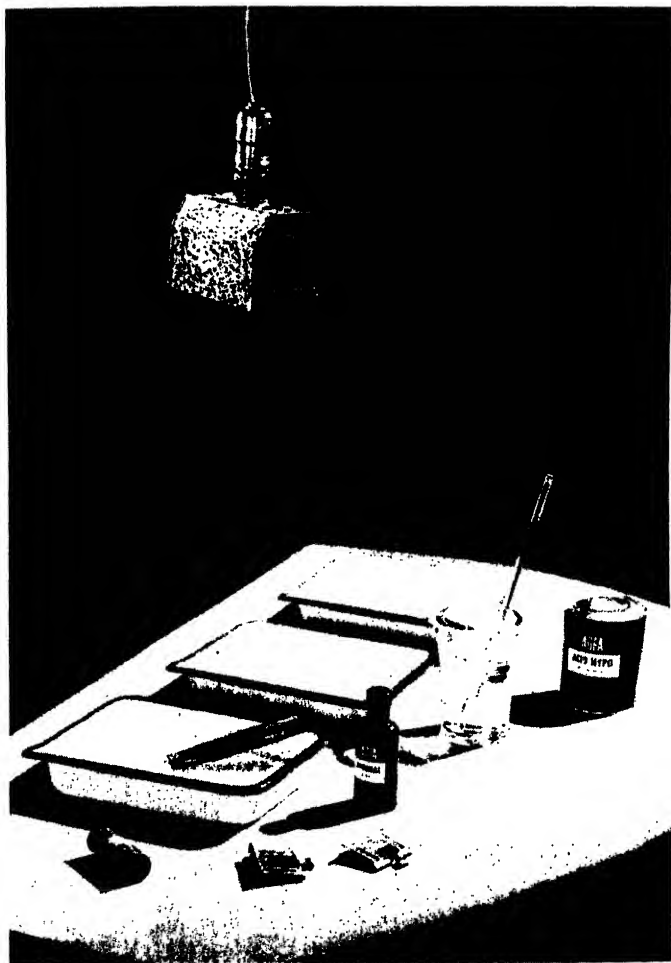
two wires in the circuit end in metal plates, each with a surface area of about one-quarter square inch, and spaced at about one millimeter separation. Pure water is a poor conductor of electricity, but the resistance of the water decreases as increasing quantities of a salt are dissolved. The elimination of the hypo can be noted progressively through the dropping of the meter needle.

Drying is usually haphazard, and leads to a lack of uniformity in negative quality. If films are always blotted and then dried with an electric dryer, a much more satisfactory uniformity is obtained. The fact that the films are kept free from dust during the process is also of great value. The advanced expert will want to keep his developers at a known degree of alkalinity, and for this purpose some hydrogen ion (pH) indicator is necessary. As a rule a simple colorimetric indicator is entirely satisfactory.

When solutions are filtered, particularly when there is a considerable amount of suspended matter to be removed, the filter paper or cotton becomes clogged and filtering is slowed up. Any laboratory supply house will supply a filter flask, funnel, and pump at a moderate cost. Attached to a faucet and with the water turned on, this simple pump creates sufficient vacuum to hasten the process by a considerable degree.

The hygrometer is not necessary when the blotting paper and electric dryer are used. When films are dried under normal room conditions it is always advisable to know the amount of existing humidity, so that circulating warm air can be introduced into the room if necessary.

One great problem which confronts all amateurs is the identification of negatives a few weeks or a few months after they are made. Films may be numbered with a regular numbering machine which perforates the film in the shape of numerals. Many amateurs have converted old check punches to this purpose. One can



Agfa Ansco

The simplest developing layout consists of three trays, thermometer, film clips, safelight, and prepared developer and fixer.

obtain a commercial device which prints the number on a negative before development by exposing an edge of the film through adjustable numeral stencils. If the exposure method is to be used, however, the Eastman X-ray record printer is convenient because of its extreme flexibility. The record printer is a light-tight box enclosing a small light bulb. The negative number or other identification is typewritten with a heavy ribbon on the extreme edge of an ordinary 3x5 filing card. This card and the film are inserted in a slot in the device, and exposure obtained by an electric switch. The number, title, or any other desired information thus becomes a part of the negative image. The card is then used as a guide in the negative file, and any additional information may be entered on it.

It is not necessary to say very much about the densitometer, as its use will be discussed in detail in a later chapter. The one important fact for us to know at this time is that the densitometer is not at all necessary for ordinary amateur processing. For the color worker, student of sensitometry, or photographer engaged in other exacting branches of negative production it is essential.

There are many other articles, particularly the small gadgets, which are to be found in every darkroom, but they are usually acquired over a considerable period of time as dictated by the need or desire of the photographer.

Darkroom Technique.

When a working place has been arranged and the essential equipment obtained, the first thing to do is to establish some kind of system. For example, if trays are used the developer should always be at one end of the row of three trays, and always thereafter it should be at the same end. Some workers prefer the

developer at the right. Others place it at the left. This is purely a matter of personal preference.

In using tanks the same procedure should always be followed, and one solution should be returned to its bottle or disposed of before the next is used in order to prevent confusion. It is necessary to preserve cleanliness at all times, although chemical cleanliness is of even greater importance than physical. Make a habit of rinsing your hands in running water immediately after touching anything in the darkroom. This is one of the easiest ways known to prevent contamination of solutions and staining of negatives. Wash every piece of equipment when you are through with it. Mop up any spilled chemicals with a damp rag. Do not let them dry, as dusting will scatter particles around the room, and eventually they will cause mysterious spots upon your negatives and prints.

This idea of system is not so much a matter of one definite system as of establishing a routine of habit which will be of greatest assistance to you in preventing serious errors later on. For that reason you should feel perfectly free to establish your own workroom layout and routine in a manner that suits you best. The photographic world is full of rules and regulations—most of them meaningless and originating in the fact that so many of us wish to tell all the rest of the world exactly how everything is to be done. If you see a routine suggested which appeals to you, adopt it by all means, but at the same time do not hesitate to make any alterations you wish. Half of the fun in photography comes in developing ideas and methods that will facilitate one's work both in the field and in the darkroom.

Weights and Measures.

There are, of course, some rules which must be observed, and among these are the quantitative ones con-

cerned with weighing and measuring. One of the first things the amateur encounters is the apparent confusion about the system of weights to be used. The **metric system** is being more and more widely used, and the **avoirdupois system** correspondingly discarded. There is a very sound reason for this—namely, that the metric system is a logical one, easily remembered, and very easily converted into various quantities. The avoirdupois is an illogical system with no apparent relationship among the various subdivisions. It is rendered even more difficult by the similar but definitely different apothecaries' and troy systems. Indeed, many of the older photographic formulas are given according to the apothecaries' or drug-store system of weights.

It is assumed at the present time that any formula given in grains and ounces is avoirdupois. Some carelessness has been observed in the use of the abbreviations **g**, **gm**, and **gr**. The abbreviation **g** should not be used because it is the cause of much confusion. Worse than that, however, **gr**, which is officially the abbreviation for **grain**, is too often used to designate the metric **gram**, for which the abbreviation **gm** is to be preferred.

The metric system is based upon the multiplication by ten. That is, starting with the **gram** we decrease in weight through the **decigram**, **centigram**, and **milligram**, each of which is one-tenth of the preceding unit. Going upward we have the **decagram**, the **hectogram**, and the **kilogram**, each one being ten times the value of the preceding one. In photography the **gram** is ordinarily the only weight unit used. The unit of weight is based upon the unit of measure by way of the unit of volume. The **gram** weight is derived from the weight of a cubic centimeter of pure water at its temperature of greatest density. The **cubic centimeter** itself is the basis for the measure of volume. One thousand cubic centimeters (or roughly, thirty-

four fluid ounces) is the larger unit, known as the liter. It might be added at this point that many graduates instead of being calibrated in cubic centimeters or cc are graduated in milliliters or ml. There is a difference between the cubic centimeter and the milliliter which is of importance in a research laboratory, but so far as the photographer is concerned he may consider the two units as identical.

If an amateur has a formula for mixing one gallon of developer and he wishes to mix a quart, the weight of each chemical must be divided by four. If the metric system has been used this is a problem of elementary arithmetic. However, if the formula has been given in avoirdupois, it is first necessary to reduce larger units, such as ounces or drams, to grains. Then the division is made, and if the balances are provided with dram weights it is necessary to reconvert the reduced formula. These are among the most obvious reasons for the preference we give the metric system. Comparisons between the two systems will be given in detail in Chapter XI.

Water Supply.

Another point which deserves more attention than it usually receives is the purity of the water available. In many cities the tap water is almost as satisfactory for photographic purposes as distilled water. In many other communities the water has a sufficient amount of mineral or organic content, or both, to affect its photographic action. Extremely hard water may contain sufficient alkali to require compensation in mixing a developer. Water with a high content of lime has a tendency to deposit a gray scum on the film, which is very difficult to remove. Iron dissolved in the water and later precipitated will very often produce small, bright blue spots on the negative. Organic materials in any quantity will be reduced by the developer, pro-

ducing disintegration and weakening the strength of the solution.

The quantity of water, if less than one gallon, should be poured through a funnel containing a small cotton filter. A visible discoloration of the cotton probably indicates organic matter, although it may be rust or sediment from pipes. A brown tint almost always indicates the presence of organic material. If a quantity of the water is boiled for ten or fifteen minutes and a white or gray deposit noticed on the sides of the vessel, the presence of undesired mineral salts is indicated.

These are simple rough-and-ready tests, and will suffice for most routine photographic procedure. However, if you have reason to suspect that your water is not absolutely pure, it is advisable to boil and then cool all water to be used in making up photographic solutions. Almost any water suitable for drinking is satisfactory for washing if a careful final cleansing is used on the negative. For highly accurate work it is desirable to use distilled water, particularly for making the solutions themselves. In certain processes, particularly those using silver or gold salts, the use of distilled water is a requirement.

In case the preceding paragraphs sound too ominous, it may be added that I have engaged in photographic processing in several different communities in nine states, and have never yet found the normal water supply unsatisfactory for this purpose, although alkali compensation was necessary in two locations.

Making Solutions.

There are many points about the mixing of solutions which the experienced amateur takes for granted, yet which are both highly important and unknown to the beginner. In the first place, strong mineral acids must be handled with extreme care. The same thing

applies to the strong alkalis, such as stronger ammonia and sodium or potassium hydroxide. The worst offender is sulfuric acid, which is used in comparatively few photographic solutions. When sulfuric acid and water are mixed, a very high temperature is produced. The temperature increase is so great that if a few drops of water are poured into a vessel of concentrated sulfuric acid an explosion will occur, and acid will be thrown over everything in the immediate vicinity. This, in several cases, has resulted in extremely painful burns caused by acid being thrown upon the hands and face of the photographer.

When mixing water and sulfuric acid, always pour the acid very slowly into the water, stirring constantly. Never pour water into the acid. Other acids heat up when mixed with water, and the same procedure is advisable in all cases, although the danger is not as great with any other acid as it is with sulfuric. As a matter of routine it is suggested that any substance, liquid or solid, which is to be dissolved in water should be poured into the water, and not vice versa.

There is a time-honored rule in photography that all formulas shall be mixed in the order in which the ingredients are listed. This rule is sometimes ignored by writers, and in many cases it is unimportant, but in the average photographic formula it is extremely important in one respect. Metol will dissolve quite readily in water, and therefore usually heads the list when it is to be used at all. As soon as the metol dissolves, a reducing solution is formed, and this solution will absorb oxygen from the air causing its oxidation. It is therefore advisable to get the sulfite into the solution as soon as possible. In fact, many laboratory workers add a small part of the sulfite as the first ingredient, although this is rarely shown in the formula itself. If any sulfite is dissolved first, it should be in very small quantity because metol dissolves with much

greater difficulty in a sulfite solution than in water alone.

There is another reason for adding the sulfite as the second ingredient. Hydroquinone is not readily soluble in water, but it is quite freely soluble in a solution of sulfite. The addition of the alkali and the restrainer, if any, fall in that order merely because they constitute the remainder to go into solution, and the developing agents dissolve better before the alkali is added.

Two common causes of difficulty in mixing developing solutions are incomplete solution of one substance before the addition of the next, and attempts to mix solutions in too highly concentrated form. Although it is not as widely published now as it was some years ago, it is an acknowledged rule in mixing photographic solutions of any kind that any one ingredient shall be thoroughly dissolved before the next is added. Some amateurs go to the extreme of dissolving each chemical in a separate small quantity of water and then mixing the separate solutions. This is an unnecessary labor; also, we have already seen that the presence of sulfite is a definite aid when dissolving hydroquinone.

The ordinary developing or fixing solution should be colorless and water clear, although many developers quickly take on a yellowish or brownish tint caused by oxidation. Any cloudiness or discoloration should be suspected, and if in moderate amount the solution should be filtered (Fig. 30). If the cloudiness is dense, the entire solution should be discarded and a new one made up. The preceding statement is subject to one exception. In many cases where an attempt is made to produce a highly concentrated solution the liquid becomes filled with a light, milk-white, curdy precipitate. If this appears, try diluting it to



Fig. 30. Photographic solutions containing suspended matter should be filtered through clean cotton before they are used.

the normal working strength before discarding the solution. Two or three minutes' vigorous stirring will usually dissolve the precipitate and clean the solution.

Many formulas call for a small amount of warm water—that is, from about 100° to 125° F. This procedure is perfectly satisfactory provided the temperature is known to be that called for in the formula. The difficulty is that many amateurs, failing to realize that body temperature is above 98° F., usually heat the water to a temperature which is nearer to 170°! The consequence, in many cases, is a partial or total decomposition of the chemicals. When a malted-milk mixer is used to compound an ordinary developer, it is quite easy to dissolve all the chemicals in cold water. As a rule, the various materials used will be dissolved almost as soon as the next ingredient can be weighed out.

There is some confusion as to the degree of accuracy necessary in making up photographic solutions. For routine negative making an error of five per cent is negligible, and very rarely will an error of ten per cent prove harmful. There is no point whatever in using a delicate analytic balance for weighing out chemicals. At the same time, quantities to be weighed are often as small as five grains, and it is obvious that the balance should respond in this case to a difference of one-quarter grain.

Many amateurs have discovered that scales aren't necessary at all! They merely pour in a certain amount of each ingredient right from the original package, and judge the amount by visual estimate! Now it is perfectly true that most of these developers will produce an image. The significant point, however, is that negatives produced in such a developer usually exhibit at least half of the errors which can be catalogued in the entire development process. This fact that almost any solution of the conventional in-

redients will produce a developer that works has contributed, more than anything else, to carelessness in compounding developers. In fact, one of the secrets for making beautiful prints is: **never be careless in compounding negative developers.**

The usual method for making up any photographic solution is to take about three-quarters of the amount of water specified, dissolve in it the indicated ingredients, and then add sufficient water to bring the total volume up to the indicated amount. At the present time it is standard practice to have as the last item of any formula the phrase "water to make." In older formulas it was quite common to see "water q.s.," which means exactly the same thing. There are certain older formulas still in use wherein the entire volume of water is given as a definite quantity at the beginning, and the chemicals added to this total quantity. As a result, a one-pint formula would often end as anything between seventeen and eighteen ounces of solution. It is understood in modern photography, however, that the quantity of water stated is the final volume and always includes the total solution of every ingredient used whether so indicated in the formula or not.

In some formulas the various ingredients are indicated as so many parts instead of definite weights—such as two parts of A, three parts of B, and one hundred parts of water. This obviously is a type of percentage solution and is almost always based upon ten, one hundred, or one thousand parts of water. This method of measurement is the source of a great deal of confusion. For example, some photographers insist upon using one hundred parts of water to which the two and three parts of A and B respectively are added, making a total of 105 parts. Other photographers are just as sure of their position when they maintain that the total of five parts of A and B should be deducted from the

hundred parts of water, so that the actual formula is based upon the use of 95 parts of water, making a total of one hundred parts.

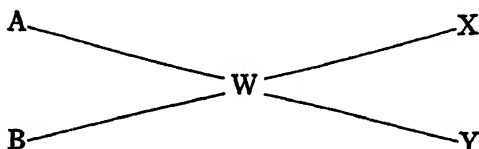
In many cases the difference is so slight that it really amounts to hair-splitting, but in some specific cases the difference is great enough to be of importance. It can be seen that these two methods are merely counterparts of the two methods using actual weights and in which the total volume of water or a sufficient quantity of water is added.

Another thing which is confusing to the beginner is the mixing of percentage solutions. When dry chemicals are used this is not so difficult, and it is even easier if the dry chemicals are to be dissolved according to the metric system. One of the easiest ways to determine the quantities for making percentage solutions is shown on the opposite page.

Another factor of importance in photographic work is the type of sodium salts used. Both the sulfite and the carbonate may be obtained in crystalline form containing a considerable amount of water of crystallization. Naturally, as so much of the mass is water, a greater weight of material in this form must be used. Partially or totally dehydrated (dry) forms of both chemicals are commonly used in this country. No particular attention need be paid to the sulfite if it conforms sufficiently to the standard, regardless of the manufacturer or method of manufacture (it is assumed, of course, that only photographic chemicals produced by reputable manufacturers will be considered for our purpose). The carbonate, however, is available in two distinct forms—the monohydrated and the anhydrous. Most photographic formulas are based upon the use of one or the other, and the form called for is usually indicated.

The crystal form of sodium carbonate (rarely called for) contains 63% water, the monohydrated

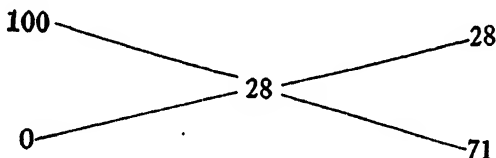
A Simple Formula for Diluting Solutions*



To use the easy criss-cross method of figuring dilutions, place at A the percentage strength of the solution to be diluted and at B the percentage strength of the solution you wish to dilute with (in the case of water, this will be 0). Place at W the percentage strength desired. Subtract W from A and place at X. Then subtract B from W and place at Y. If you take X parts of A and Y parts of B and mix, you will have a solution of the desired strength W.

For example:

To dilute glacial acetic acid to 28%.



Take 28 parts 99% acid and 72 parts water. (For calculations of this nature glacial acetic acid may be considered as 100%.)

* From "The Chemistry of Photography," published by Mallinckrodt Chemical Works.

form contains 15% water, and the dry (desiccated or anhydrous) form contains about 1 or 2% water. The quantity of carbonate called for is calculated to give the required alkalinity providing the form specified is used. Therefore, when one form is substituted for another it is necessary to make a conversion in order

to achieve the desired result. This is easily done; use 15% more monohydrated when desiccated is specified, or 15% less desiccated when monohydrated is specified. Of course this will not give accurate results, but in the case of carbonate, this rough-and-ready conversion is quite close enough to give complete satisfaction.

The actual mixing of a solution should be done in a vessel the capacity of which is at least twice that of the amount to be mixed. It should be large enough to give room for vigorous stirring if a mechanical mixer is not used. There should be no danger of spilling any of the solution, both as a matter of neatness and because any appreciable amount of waste will alter the strength of the solution. Small amounts of developer may be mixed in a sixteen-ounce graduate, but either a thirty-two-ounce graduate or a thirty-two-ounce measuring jug is usually more convenient. Some technicians prefer to use a bottle of about double the necessary capacity, and after the addition of each ingredient the bottle is closed and shaken violently for a short period. It is doubtful if this produces any better or more rapid solution than stirring, and unless a mechanical agitator is available it is far more laborious than the use of the conventional stirring rod.

When certain dirt particles or other foreign materials fall into dry chemicals and this material is known to be insoluble (wood, lint, pieces of cardboard, oiled paper, etc.), their presence is ignored unless of sufficient volume to affect the weight. When the solution is made it is poured through a cotton filter and all these foreign materials are effectively removed. About the only chemical in which this condition is normally found is bulk hypo. All the dry chemicals used by the amateur should be kept in glass stock bottles with screw caps or glass stoppers. Uniform bottle sets are regarded by most amateurs as a luxury, but once they



Fig. 31. Bottles which originally contained food products can be cleaned up and used in the darkroom for storing solutions.

have been used no one will try to get along without them.

When sodas are purchased in five-pound (or larger) cans, only about one pound is removed at a time for actual use. It is a mistake, however, to keep one pound and smaller stock packages for constant use, particularly when the containers are of cardboard. Bottles may be purchased in any desired size or shape, but many amateurs make up very presentable uniform sets by carefully cleaning bottles or glass jars in which food and drug products have been purchased. Many of these containers are of a type and shape which lend themselves to this purpose (Fig. 31).

It is extremely important that bottles and other containers used in the darkroom be labeled. This will prevent mistakes as well as waste in compounding formulas or preparing working solutions. Those bottles which are used for stock developers may be provided with additional labels bearing the formula to facilitate mixing when a new supply is needed. In order to keep labels clean and prevent their being soaked off when the bottles are washed, they may be coated with ordinary varnish, as shown in Fig. 32. This provides them with a protective surface that will resist water and ordinary darkroom solutions. The varnish should be applied beyond the edge of the label so that no moisture can get between the label and the bottle. A temporary sticker is often pasted onto bottles containing developer and hypo to provide a place for recording the date on which the solution was made and the number of times used.

One other question often arises, namely, the type of dry chemical to be used. It is advisable whenever possible to purchase "photographic" chemicals. The chemicals listed in this classification are not necessarily chemically pure, but any impurities present will not affect the photographic reaction. In case of emer-

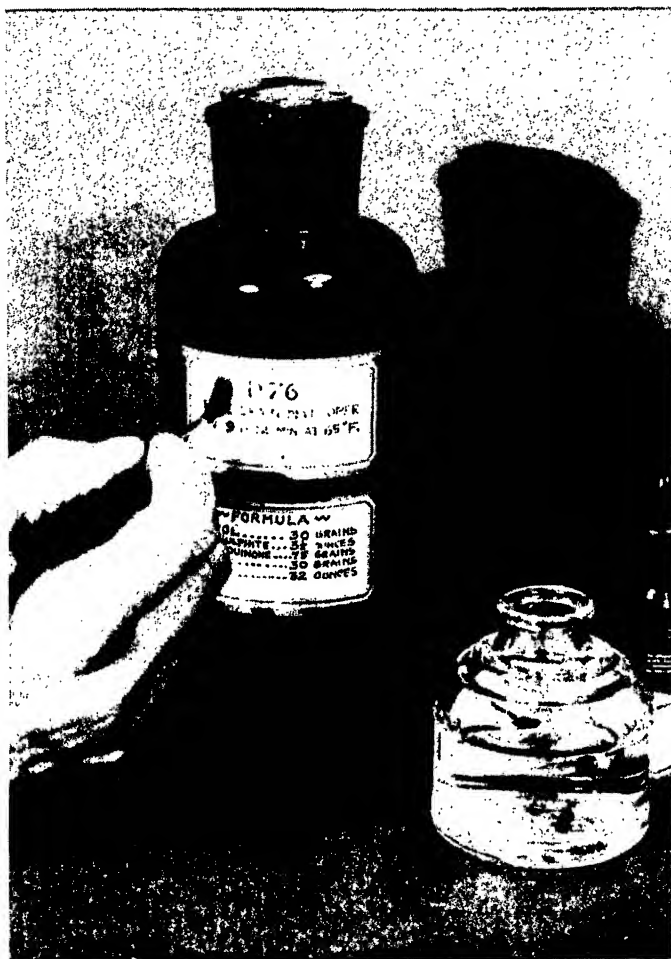


Fig. 32. To protect them from dirt and liquids, labels on the darkroom bottles and other containers are coated with varnish.

gency, when the regular photo chemicals cannot be obtained, either the chemically pure or reagent grade should be used. As a rule these grades cost considerably more than the photo-pure, but very rarely will the commercial grades be found satisfactory.

Fresh dry chemicals should be used, and purchases made so that a supply for not more than six months is obtained. I have used metol ten years old and once tested twenty-year-old Adurol which was good, but it is safer to use chemicals which are not more than a half-year old. Even dry chemicals tend to react to atmospheric moisture, decomposing into other and simpler compounds. This is particularly true of many sodium and potassium salts used in photography.

To sum up, if photo-pure chemicals are used and any water, not definitely known to be satisfactory, is boiled before use, little difficulty is to be anticipated in making up solutions.

And now, before going ahead with the discussion of specific formulas, a word concerning weights and a conversion table. While the superiority of the metric system is unquestionable, as was mentioned before, most amateur darkrooms are equipped with scales, graduates, and storage bottles designed for avoirdupois. Therefore, this system will be used in discussing formulas. Those who use the metric system will find the following conversion factors useful.

To Convert	To	Multiply	By Factor
Cubic centimeters	Fluid ounces	cc	0.03381
Fluid ounces	Ml or cc	fl. oz.	29.573
Quarts	Liters	qts.	0.9463
Liters	Quarts	liters	1.0567
Grains	Grams	grains	0.0648
Grams	Grains	grams	15.4324
Ounces	Grams	ounces	28.3495
Grams	Ounces	grams	0.0353
Grains per 32 ozs.	Grams per liter	gr. per 32 oz.	0.06847
Grams per liter	Grains per 32 ozs.	gm. per 1.	14.60

Mixing the Developer.

With the foregoing points in mind you are now ready to mix the first developer. A typical developer for general negative use is the medium-grain M-Q borax formula. It utilizes metol and hydroquinone for reducing agents; the alkali used is ordinary borax (borax is one exception to the general rule, because ordinary kitchen borax is entirely satisfactory). Sulfite is used as the accelerator, but in an unusually large quantity, while no restrainer at all is used. The formula for this developer is:

Metol-Hydroquinone-Borax Developer (Eastman D-76)

	Avoirdupois	Metric
Water (125° F. or 52° C.).....	24 ounces.....	750.0 CC
Metol.....	29 grains.....	2.0 grams
Sodium sulfite, dry.....	3 oz., 145 grains.....	100.0 grams
Hydroquinone.....	73 grains.....	5.0 grams
Borax.....	29 grains.....	2.0 grams
Water to make.....	32 ounces.....	1.0 liter

This formula is quite interesting because the amount of borax can be altered within a wide range for increasing the activity of the developer. When as much as ten times the specified quantity of borax is used, the developing time will be about half normal. To obtain the maximum action from this developer Kodalk* is used instead of borax in the quantity specified in the formula.

Assuming that this developer is to be compounded from separate ingredients, you will need all the chemicals listed. The metol and hydroquinone may be in one-ounce or four-ounce packages, and the other chemicals in one-pound packages. These chemicals are transferred to suitable glass bottles or jars. A table is used conveniently close to the sink or other source of running water. The photographic scales

* Kodalk is a proprietary alkali of the Eastman Kodak Co. Its activity is intermediate between that of carbonate and borax.

are placed on this table; the rider on the beam of the scale is placed at zero; and the trays allowed to come to rest. They probably will not indicate a balance—that is, one side will be lower than the other. Under the pans will be found little adjusting nuts, each on a short threaded rod. Turning these nuts causes them to move in or out. The nut under the lower pan is screwed toward the center of the balance while the one under the higher pan is screwed outwardly. A little experimenting will enable you to reach an adjustment at which the scale pans are exactly balanced as shown by the balance pointer. It is important that the pans be approximately level, as any other position will throw them out of balance.

If balances of a better quality than the ordinary photographic scales are used they will probably have a lever which in one position clamps the pans so that they can't move, and in the other position permits them to swing freely. Although scales of this quality are not at all necessary, they are often used by amateurs. In using them do not permit the pans to swing freely, but add the chemicals a small amount at a time, and after each addition release the lever; continue this until the scales are approximately in balance.

In a chemical laboratory where a wide variety of materials is handled, it is the rule to cut two pieces of paper and place them on the scale pans before the actual weighing is done. This is a little more trouble than using the unprotected pan, but it does make for cleanliness and it has one convenience of its own, namely, that of lifting and pouring chemicals into the water (see Fig. 33).

When this system is used, a piece of smooth paper is folded and creased sharply. The three free sides are cut on a trimming board, each to about $3\frac{1}{2}$ inches. When this has been done the creased edge is also cut away. This leaves two pieces of paper of exactly the



Fig. 33. Paper on left-hand pan facilitates handling of dry chemicals. Its weight is offset by folded piece on other pan.

same size, and for our purposes they will be sufficiently near the same weight. One of these pieces of paper is folded down the center, then opened and placed on the pan which is to receive the chemicals. The other piece of paper is merely laid on the unused pan as a counterbalance. The metal is then weighed by pouring it on the paper instead of into the pan. When the correct quantity has been weighed the paper is removed from the balances and the crease formed by folding the sheet serves as a guiding chute for pouring the metal into the water. (See Fig. 34).

In making up the M.Q. - Borax formula we are considering, five identical sheets of paper should be cut. One of these remains as a counterbalance while each of the remaining four is used for a separate chemical. The use of the paper is of questionable value in routine processing, but it does add to the cleanliness of the workroom and will aid in preserving the appearance and utility of the balance.

With a conventional photographic balance (which we will assume is graduated in the avoirdupois system) the rider—that is, the little block of metal which slides on the scale beam—is placed at the figure which indicates 29 grains. This causes the pan on the right to swing down while the one on the left rises. Using a powder scoop or spoon, pour the metal slowly into the upper pan until it just starts to swing. The scoop is then held so that by tapping it a few grains of the chemical will be shaken off; this is continued until the pans come into perfect balance.

About 24 ounces of water are placed in a 32-ounce graduate, and the metal poured into the water. The water is stirred vigorously, and the metal will readily dissolve. The beginner is warned against the use of warm water because it is usually used too hot. For twenty years our laboratory has used solutions made up at room temperature, and tests have shown that



Fig. 34. As each ingredient is added, the solution is stirred vigorously until the chemical has been completely dissolved.

there is unquestionably a greater spontaneous oxidation at higher temperatures. The use of an electric mixer will enable you to dissolve developer ingredients in room-temperature water (as low as 60° F.) just as quickly as they can be dissolved in hot water by hand stirring. The low cost of the kitchen type of electric mixer (about one dollar) makes it easily available to every amateur. The metal stirring rods can be covered with ordinary electrician's rubber tape.

The amateur should not keep stock solutions of developers on hand. They will oxidize. Glass marbles and other devices to fill bottles are makeshifts. When you have a job to do, make up fresh developer from dry chemicals. (Borax-type developers are the one exception; these are kept in perpetual stock.)

When the metal has been dissolved, the sulfite is weighed out. As 3 ounces and 145 grains are to be used, the rider has not sufficient range, so it is returned to zero at the left end of the scale beam. The one- and two-ounce weights are removed from their receptacle in the baseboard of the balance and placed in the right-hand pan, and the sliding weight on the scale arm moved to the point indicating 45 grains. If paper protectors are used the weights are placed on top of the paper. Care will have to be used in adding the sulfite, as the quantity called for almost fills the scale pan. If you prefer you may weigh the sulfite in two lots.

The sulfite should be added to the water rather slowly while the solution is aided by vigorous stirring. The sulfite, although readily soluble in water in ordinary quantities, will not dissolve at once. However, if a mixer is used the sulfite will dissolve completely in a few moments. Stirring should not be stopped for at least two or three minutes after the last of the sulfite has been added. If poured in rapidly without stirring the water, it will cake at the bottom of the graduate

and a much longer time will be required to effect solution.

When the sulfite is dissolved, the weights are removed from the pan, the rider set at 23 grains, and a 50-grain weight placed in the pan. The weight indicated by the balance is the sum of the weight indicated on the scale beam plus any weight in the right-hand pan.

The hydroquinone is used in a small quantity and does not tend to stick together, so it may be added all at once. It does not dissolve as readily as any of the other chemicals used, but if it is added after the sulfite it will eventually dissolve. The last step is to add the borax, which is weighed out exactly the same as was the metol. It presents no particular difficulties as it dissolves quite readily. When the developer contains no more trace of solid material, a sufficient amount of cold water is added to bring the quantity up to 32 ounces. If there is any trace of undissolved material of any kind in the solution, it should be filtered through cotton or filter paper before pouring it into the stock bottle.

Fixing Bath.

When the developer is prepared the next step is to make the fixing bath. Unless space is at a premium it is advisable to make the hypo in one-half-gallon or one-gallon quantities. There are several types of fixing baths, but the one we will use is the old reliable acid hardening bath. This is made in two parts. The first consists of one pound of hypo dissolved in 40 ounces of water.

The hardening bath is made by adding one ounce each of sulfite, glacial acetic acid, and white alum to seven ounces of water. Dissolve in the order given and add to the hypo solution, which is then made up to

a total of 64 ounces. Here we have a departure from the ordinary instructions. We want a 25 per cent hypo solution and to obtain this it is necessary to have one pound of hypo in 64 ounces of finished solution. Therefore the hardener is added to the hypo solution and the whole made up to a total volume of 64 ounces.

The easiest way to dissolve the hypo is to make a

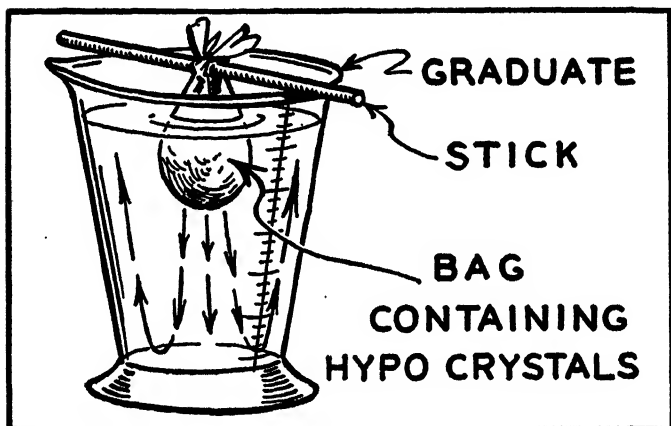


Fig. 35. Hypo can be dissolved easily if it is placed in a cloth bag and suspended in water. The method is described in the text.

small bag of thin but closely woven cotton cloth. The bag should have a capacity of considerably more than the amount of hypo you intend to use. The hypo is poured into the bag, which is then tied with a length of cord and suspended in the top of the graduate or other mixing vessel. A hypo solution is so much heavier than water that the hypo dissolving from the bag which is suspended at the surface drops down to the bottom of the mixing vessel, thus permitting the access of more fresh water to the undissolved hypo.

This sets up a current, with the result that the hypo dissolves by itself about as rapidly as could be done by conventional stirring (see Fig. 35).

In mixing the hardener it is usual to prepare a 28 per cent acetic acid from the glacial form by adding eight parts of water to three parts of the glacial acid (or 72 to 28, to be more exact). In practice this has been found to be unnecessary. The amount of water used for the hardener is increased from five ounces to seven ounces. This makes the sulfite easier to dissolve. To this is added one ounce of glacial acetic acid and then one ounce of alum is dissolved, completing the hardener. The result is a hardener which is definitely more acid than the normal formula calls for. However, the formula is easy to remember as it contains only one ounce of each of the three ingredients. I have used it for a number of years, and have not found that the additional acidity imparts any harmful property to the solution.

The two solutions which you have now prepared—developer and fixing bath—are the basic ones for your work, and with them you are actually ready to develop your first negative.

